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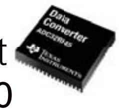

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RADAR TECHNOLOGIES ISSUE

# Tracking RADAR TECH ADVANCES


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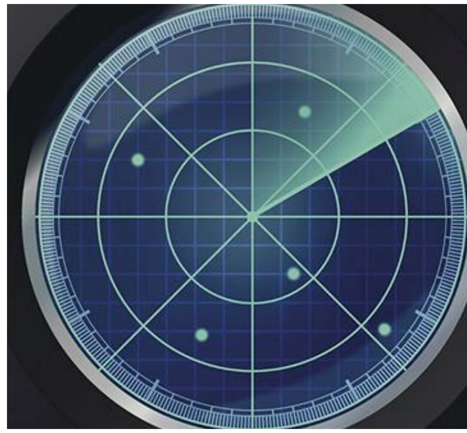
## FEATURES





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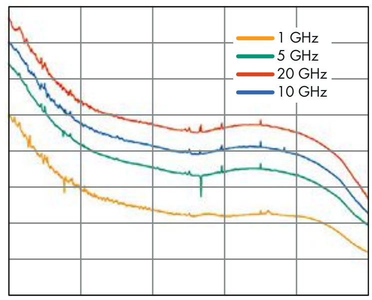


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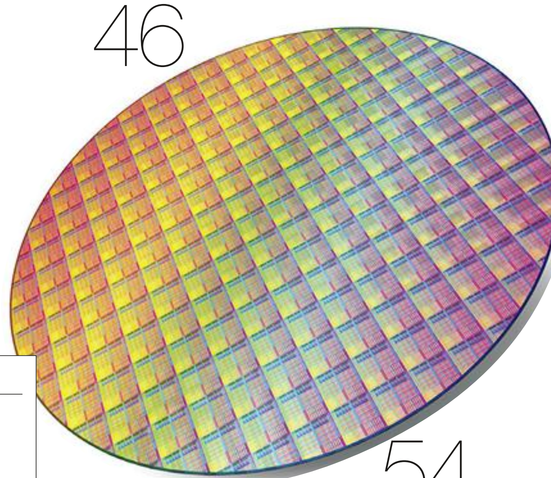

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*DEFENSE ELECTRONICS*
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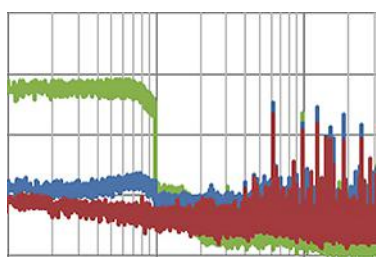

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**EXTEND YOUR REACH**

Compass Technology Group using R140 to measure reflection properties of EMI absorber materials

**R60** (new)

**R140**

**R54**

US Patent 9,291,657

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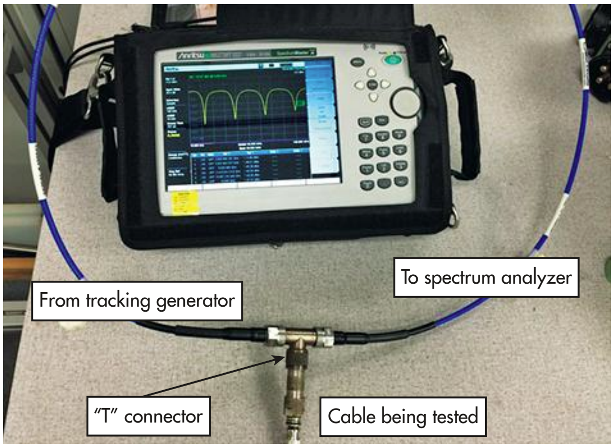



## METHOD FINDS FAULTS IN COAXIAL CABLES

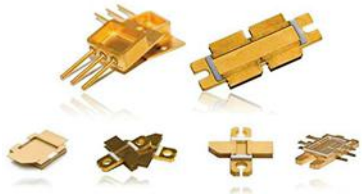
*http://mwrf.com/systems/method-finds-faults-coaxial-cables*

This straightforward technique works in the frequency domain without need of exotic test equipment to accurately find the distance to a fault in RF/microwave coaxial cables.

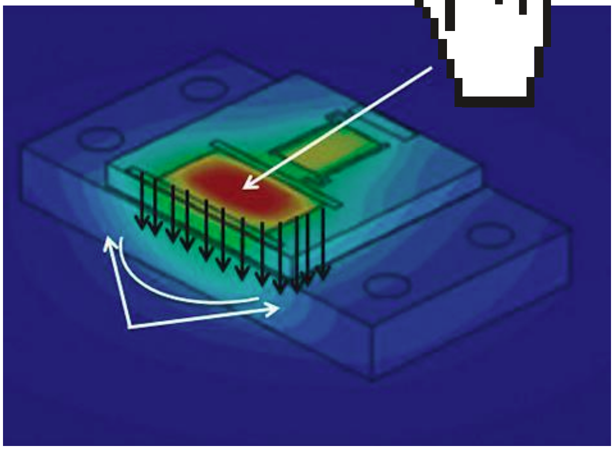
## POWER DEMANDS PUT THE PRESSURE ON PACKAGING

*http://mwrf.com/components/power-demands-put-pressure-packaging*

Higher power densities and frequencies are pushing packages to their limits, while emerging wireless applications such as IoT and 5G crave lower-cost housings.





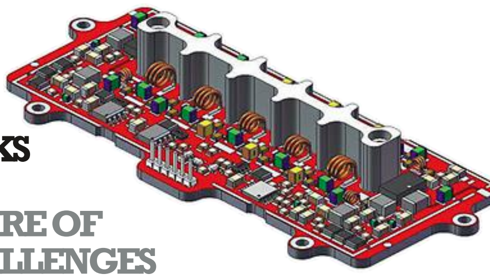


## DESIGN AND TEST TIPS TO HELP EXTEND PRODUCT LIFETIMES

*http://mwrf.com/passive-components/these-design-and-test-tips-help-extend-product-lifetimes*

Understanding the impact of selecting different materials and manufacturing processes can separate standard high-power resistive components from those designed and tested for true high-reliability applications.

## HIGH-POWER SWITCHED FILTER BANKS RAISE THE TEMPERATURE OF DESIGN CHALLENGES



*http://mwrf.com/active-components/high-power-switched-filter-banks-raise-temperature-design-challenges*

For high-power switched filter banks, the power and voltage stresses of rapidly switching at high power—along with achieving low insertion loss and high out-of-band rejection—require novel strategies to support these emerging needs.

# Editorial

CHRIS DEMARTINO
Technical Editor
chris.demartino@penton.com

# Design Software Leaves its Mark

Engineers today can take advantage of design software to simulate everything from extremely simple to highly elaborate designs. This was demonstrated at this year's IEEE International Microwave Symposium (IMS), as a number of software providers showcased their impressive capabilities. With software playing such a critical role, the companies that provide these tools continue to push the envelope by offering more efficient solutions than before.

For example, Sonnet (www.sonnetsoftware.com) recently enhanced its capabilities with the introduction of Release 16 (V16). A major benefit of V16 is integration with the Modelithics (www.modelithics.com) CLR Library for Sonnet. This library contains a large number of simulation models, allowing users to easily include more models in their Sonnet simulations. Modelithics integration is not the only new feature in V16: Maximum thread count for the high performance solver (HPS) increased from 32 to 48, boosting the speed of larger projects by as much as 50%.

One company that may not immediately come to mind when discussing high-frequency design software is MathWorks (www.mathworks.com). Of course, many associate the company with MATLAB, which is used by companies and universities everywhere. But the company is also focusing specifically on RF design, demonstrated by the RF Toolbox software. The RF Toolbox allows users to specify filters, transmission lines, amplifiers, and mixers directly or by their physical properties. It can read and write touchstone file formats, meaning that, say, S-parameter data obtained from a vector network analyzer (VNA) can be imported and plotted.

Furthermore, the RF Budget Analyzer was recently introduced in the RF Toolbox. The former is a helpful tool that allows system designers to build and analyze a cascade of RF components. It can calculate cascaded gain, noise figure, and third-order intercept-point (IP3). This is a nice tool that is an improvement over using a spreadsheet, which is often used in these situations. In addition, the RF Budget Analyzer works together with the company's SimRF software.

Of course, companies like Keysight (www.keysight.com), National Instruments (www.ni.com), and ANSYS (www.ansys.com) are well-known providers of high-frequency design software. COMSOL (www.comsol.com)—with its Multiphysics software—is another company that offers engineers an advanced modeling and simulation tool. And Computer Simulation Technology (www.cst.com) just announced a free student version of its electromagnetic (EM) simulation software. With all of these and other options, those who use RF/microwave design software now have many tools at their disposal. mw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EDITORIAL

CONTENT DIRECTOR: **NANCY K. FRIEDRICH** nancy.friedrich@penton.com
TECHNICAL CONTRIBUTOR: **JACK BROWNE** jack.browne@penton.com
TECHNICAL ENGINEERING EDITOR: **CHRIS DeMARTINO** chris.demartino@penton.com
CONTENT PRODUCTION DIRECTOR: **MICHAEL BROWNE** michael.browne@penton.com
PRODUCTION EDITOR: **JEREMY COHEN** jeremy.cohen@penton.com
CONTENT PRODUCTION SPECIALIST: **ROGER ENGELKE** roger.engelke@penton.com
CONTENT OPTIMIZATION SPECIALIST: **WES SHOCKLEY** wes.shockley@penton.com
ASSOCIATE CONTENT PRODUCER: **LEAH SCULLY** leah.scully@penton.com
ASSOCIATE CONTENT PRODUCER: **JAMES MORRA** james.morra@penton.com

ART DEPARTMENT

GROUP DESIGN DIRECTOR: **ANTHONY VITOLO** tony.vitolo@penton.com
SENIOR ARTIST: **JIM MILLER** jim.miller@penton.com
CONTRIBUTING ART DIRECTOR **RANDALL L. RUBENKING** randall.rubenking@penton.com

PRODUCTION

GROUP PRODUCTION MANAGER: **CAREY SWEETEN** carey.sweeten@penton.com
PRODUCTION MANAGER: **VICKI MCCARTY** vicki.mccarty@penton.com
CLASSIFIED PRODUCTION COORDINATOR: **LINDA SARGENT** linda.sargent@penton.com

AUDIENCE MARKETING

USER MARKETING DIRECTOR: **BRENDA ROODE** brenda.roode@penton.com
USER MARKETING MANAGER: **DEBBIE BRADY** debbie.brady@penton.com
FREE SUBSCRIPTION/STATUS OF SUBSCRIPTION/ADDRESS CHANGE/MISSING BACK ISSUES
**T** | 866.505.7173 microwaves&RF@halldata.com **F** | 847.763.9673

SALES & MARKETING

MANAGING DIRECTOR: **TRACY SMITH** **T** | 913.967.1324 **F** | 913.514.6881
tracy.smith@penton.com

REGIONAL SALES REPRESENTATIVES

**GREGORY MONTGOMERY** **T** | 480.254.5540 gregory.montgomery@penton.com
AK, CA, CO, ID, MT, ND, NV, OR, SD, UT, WA, WI, WY, W/CANADA: **JAMIE ALLEN** **T** | 415.608.1959
**F** | 913.514.3667 jamie.allen@penton.com
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LIST RENTALS:
SMARTREACH CLIENT SERVICES MANAGER: **DAVID SICKLES** **T** | (212) 204 4379
david.sickles@penton.com

ONLINE

PRODUCT DEVELOPMENT DIRECTOR: **RYAN MALEC** ryan.malec@penton.com

DESIGN ENGINEERING & SOURCING GROUP

EXECUTIVE DIRECTOR OF CONTENT AND USER ENGAGEMENT: **NANCY K. FRIEDRICH**
GROUP DIRECTOR OF OPERATIONS: **CHRISTINA CAVANO**
GROUP DIRECTOR OF MARKETING: **JANE COOPER**

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CHIEF EXECUTIVE OFFICER: **DAVID KIESELSTEIN** david.kieselstein@penton.com
CHIEF FINANCIAL OFFICER: **NICOLA ALLAIS** nicola.allais@penton.com
INDUSTRY GROUP, PRESIDENT: **PAUL MILLER** paul.miller@penton.com
1166 AVENUE OF THE AMERICAS, 10TH FLOOR NEW YORK, NY 10036 **T** | 212.204.4200

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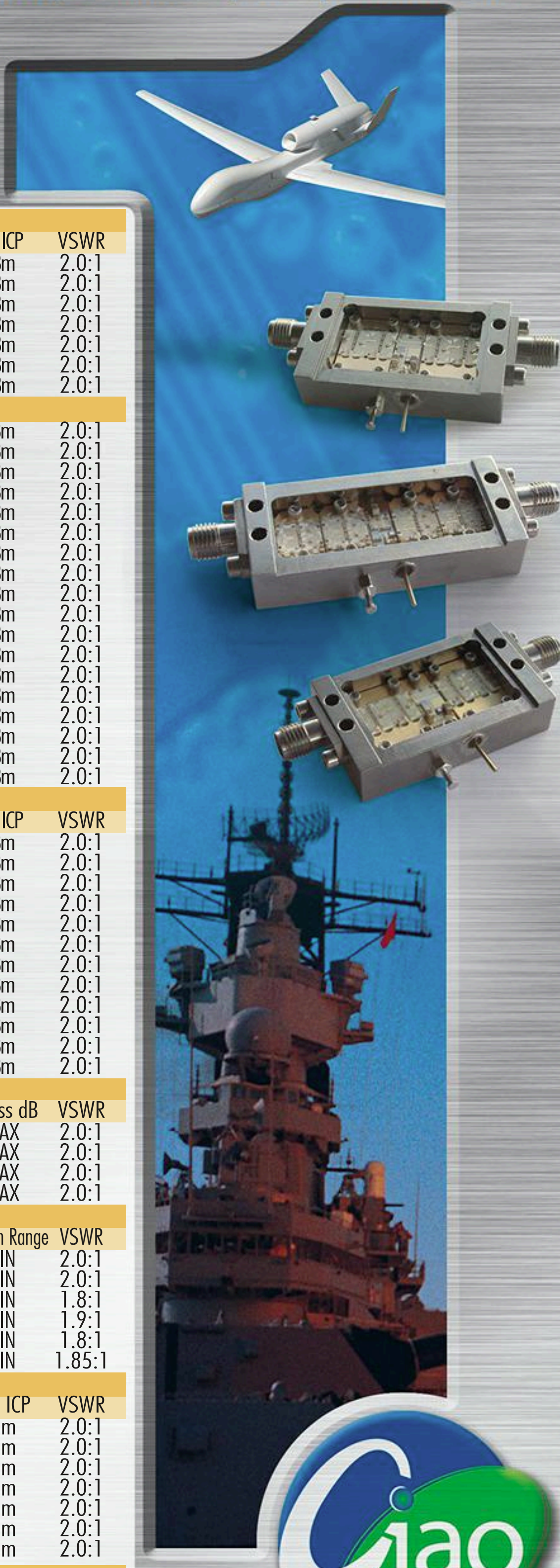

### OCTAVE BAND LOW NOISE AMPLIFIERS

| Model No. | Freq (GHz) | Gain (dB) MIN | Noise Figure (dB) | Power-out @ P1-dB | 3rd Order ICP | VSWR |
|---|---|---|---|---|---|---|
| CA01-2110 | 0.5-1.0 | 28 | 1.0 MAX, 0.7 TYP | +10 MIN | +20 dBm | 2.0:1 |
| CA12-2110 | 1.0-2.0 | 30 | 1.0 MAX, 0.7 TYP | +10 MIN | +20 dBm | 2.0:1 |
| CA24-2111 | 2.0-4.0 | 29 | 1.1 MAX, 0.95 TYP | +10 MIN | +20 dBm | 2.0:1 |
| CA48-2111 | 4.0-8.0 | 29 | 1.3 MAX, 1.0 TYP | +10 MIN | +20 dBm | 2.0:1 |
| CA812-3111 | 8.0-12.0 | 27 | 1.6 MAX, 1.4 TYP | +10 MIN | +20 dBm | 2.0:1 |
| CA1218-4111 | 12.0-18.0 | 25 | 1.9 MAX, 1.7 TYP | +10 MIN | +20 dBm | 2.0:1 |
| CA1826-2110 | 18.0-26.5 | 32 | 3.0 MAX, 2.5 TYP | +10 MIN | +20 dBm | 2.0:1 |

### NARROW BAND LOW NOISE AND MEDIUM POWER AMPLIFIERS

| Model No. | Freq (GHz) | Gain (dB) MIN | Noise Figure (dB) | Power-out @ P1-dB | 3rd Order ICP | VSWR |
|---|---|---|---|---|---|---|
| CA01-2111 | 0.4 - 0.5 | 28 | 0.6 MAX, 0.4 TYP | +10 MIN | +20 dBm | 2.0:1 |
| CA01-2113 | 0.8 - 1.0 | 28 | 0.6 MAX, 0.4 TYP | +10 MIN | +20 dBm | 2.0:1 |
| CA12-3117 | 1.2 - 1.6 | 25 | 0.6 MAX, 0.4 TYP | +10 MIN | +20 dBm | 2.0:1 |
| CA23-3111 | 2.2 - 2.4 | 30 | 0.6 MAX, 0.45 TYP | +10 MIN | +20 dBm | 2.0:1 |
| CA23-3116 | 2.7 - 2.9 | 29 | 0.7 MAX, 0.5 TYP | +10 MIN | +20 dBm | 2.0:1 |
| CA34-2110 | 3.7 - 4.2 | 28 | 1.0 MAX, 0.5 TYP | +10 MIN | +20 dBm | 2.0:1 |
| CA56-3110 | 5.4 - 5.9 | 40 | 1.0 MAX, 0.5 TYP | +10 MIN | +20 dBm | 2.0:1 |
| CA78-4110 | 7.25 - 7.75 | 32 | 1.2 MAX, 1.0 TYP | +10 MIN | +20 dBm | 2.0:1 |
| CA910-3110 | 9.0 - 10.6 | 25 | 1.4 MAX, 1.2 TYP | +10 MIN | +20 dBm | 2.0:1 |
| CA1315-3110 | 13.75 - 15.4 | 25 | 1.6 MAX, 1.4 TYP | +10 MIN | +20 dBm | 2.0:1 |
| CA12-3114 | 1.35 - 1.85 | 30 | 4.0 MAX, 3.0 TYP | +33 MIN | +41 dBm | 2.0:1 |
| CA34-6116 | 3.1 - 3.5 | 40 | 4.5 MAX, 3.5 TYP | +35 MIN | +43 dBm | 2.0:1 |
| CA56-5114 | 5.9 - 6.4 | 30 | 5.0 MAX, 4.0 TYP | +30 MIN | +40 dBm | 2.0:1 |
| CA812-6115 | 8.0 - 12.0 | 30 | 4.5 MAX, 3.5 TYP | +30 MIN | +40 dBm | 2.0:1 |
| CA812-6116 | 8.0 - 12.0 | 30 | 5.0 MAX, 4.0 TYP | +33 MIN | +41 dBm | 2.0:1 |
| CA1213-7110 | 12.2 - 13.25 | 28 | 6.0 MAX, 5.5 TYP | +33 MIN | +42 dBm | 2.0:1 |
| CA1415-7110 | 14.0 - 15.0 | 30 | 5.0 MAX, 4.0 TYP | +30 MIN | +40 dBm | 2.0:1 |
| CA1722-4110 | 17.0 - 22.0 | 25 | 3.5 MAX, 2.8 TYP | +21 MIN | +31 dBm | 2.0:1 |

### ULTRA-BROADBAND & MULTI-OCTAVE BAND AMPLIFIERS

| Model No. | Freq (GHz) | Gain (dB) MIN | Noise Figure (dB) | Power-out @ P1-dB | 3rd Order ICP | VSWR |
|---|---|---|---|---|---|---|
| CA0102-3111 | 0.1-2.0 | 28 | 1.6 Max, 1.2 TYP | +10 MIN | +20 dBm | 2.0:1 |
| CA0106-3111 | 0.1-6.0 | 28 | 1.9 Max, 1.5 TYP | +10 MIN | +20 dBm | 2.0:1 |
| CA0108-3110 | 0.1-8.0 | 26 | 2.2 Max, 1.8 TYP | +10 MIN | +20 dBm | 2.0:1 |
| CA0108-4112 | 0.1-8.0 | 32 | 3.0 MAX, 1.8 TYP | +22 MIN | +32 dBm | 2.0:1 |
| CA02-3112 | 0.5-2.0 | 36 | 4.5 MAX, 2.5 TYP | +30 MIN | +40 dBm | 2.0:1 |
| CA26-3110 | 2.0-6.0 | 26 | 2.0 MAX, 1.5 TYP | +10 MIN | +20 dBm | 2.0:1 |
| CA26-4114 | 2.0-6.0 | 22 | 5.0 MAX, 3.5 TYP | +30 MIN | +40 dBm | 2.0:1 |
| CA618-4112 | 6.0-18.0 | 25 | 5.0 MAX, 3.5 TYP | +23 MIN | +33 dBm | 2.0:1 |
| CA618-6114 | 6.0-18.0 | 35 | 5.0 MAX, 3.5 TYP | +30 MIN | +40 dBm | 2.0:1 |
| CA218-4116 | 2.0-18.0 | 30 | 3.5 MAX, 2.8 TYP | +10 MIN | +20 dBm | 2.0:1 |
| CA218-4110 | 2.0-18.0 | 30 | 5.0 MAX, 3.5 TYP | +20 MIN | +30 dBm | 2.0:1 |
| CA218-4112 | 2.0-18.0 | 29 | 5.0 MAX, 3.5 TYP | +24 MIN | +34 dBm | 2.0:1 |

### LIMITING AMPLIFIERS

| Model No. | Freq (GHz) | Input Dynamic Range | Output Power Range Psat | Power Flatness dB | VSWR |
|---|---|---|---|---|---|
| CLA24-4001 | 2.0 - 4.0 | -28 to +10 dBm | +7 to +11 dBm | +/- 1.5 MAX | 2.0:1 |
| CLA26-8001 | 2.0 - 6.0 | -50 to +20 dBm | +14 to +18 dBm | +/- 1.5 MAX | 2.0:1 |
| CLA712-5001 | 7.0 - 12.4 | -21 to +10 dBm | +14 to +19 dBm | +/- 1.5 MAX | 2.0:1 |
| CLA618-1201 | 6.0 - 18.0 | -50 to +20 dBm | +14 to +19 dBm | +/- 1.5 MAX | 2.0:1 |

### AMPLIFIERS WITH INTEGRATED GAIN ATTENUATION

| Model No. | Freq (GHz) | Gain (dB) MIN | Noise Figure (dB) | Power-out @ P1-dB | Gain Attenuation Range | VSWR |
|---|---|---|---|---|---|---|
| CA001-2511A | 0.025-0.150 | 21 | 5.0 MAX, 3.5 TYP | +12 MIN | 30 dB MIN | 2.0:1 |
| CA05-3110A | 0.5-5.5 | 23 | 2.5 MAX, 1.5 TYP | +18 MIN | 20 dB MIN | 2.0:1 |
| CA56-3110A | 5.85-6.425 | 28 | 2.5 MAX, 1.5 TYP | +16 MIN | 22 dB MIN | 1.8:1 |
| CA612-4110A | 6.0-12.0 | 24 | 2.5 MAX, 1.5 TYP | +12 MIN | 15 dB MIN | 1.9:1 |
| CA1315-4110A | 13.75-15.4 | 25 | 2.2 MAX, 1.6 TYP | +16 MIN | 20 dB MIN | 1.8:1 |
| CA1518-4110A | 15.0-18.0 | 30 | 3.0 MAX, 2.0 TYP | +18 MIN | 20 dB MIN | 1.85:1 |

### LOW FREQUENCY AMPLIFIERS

| Model No. | Freq (GHz) | Gain (dB) MIN | Noise Figure dB | Power-out @ P1-dB | 3rd Order ICP | VSWR |
|---|---|---|---|---|---|---|
| CA001-2110 | 0.01-0.10 | 18 | 4.0 MAX, 2.2 TYP | +10 MIN | +20 dBm | 2.0:1 |
| CA001-2211 | 0.04-0.15 | 24 | 3.5 MAX, 2.2 TYP | +13 MIN | +23 dBm | 2.0:1 |
| CA001-2215 | 0.04-0.15 | 23 | 4.0 MAX, 2.2 TYP | +23 MIN | +33 dBm | 2.0:1 |
| CA001-3113 | 0.01-1.0 | 28 | 4.0 MAX, 2.8 TYP | +17 MIN | +27 dBm | 2.0:1 |
| CA002-3114 | 0.01-2.0 | 27 | 4.0 MAX, 2.8 TYP | +20 MIN | +30 dBm | 2.0:1 |
| CA003-3116 | 0.01-3.0 | 18 | 4.0 MAX, 2.8 TYP | +25 MIN | +35 dBm | 2.0:1 |
| CA004-3112 | 0.01-4.0 | 32 | 4.0 MAX, 2.8 TYP | +15 MIN | +25 dBm | 2.0:1 |

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## MEASURING THE QUALITY OF TEST EQUIPMENT

Test equipment is an important part of any RF/microwave engineer's life. Most of us work near a bench that is stacked with a couple of signal generators, at least one good scope, and a variety of different signal analyzers. Engineers who are lucky enough will have access to a VNA for S-parameter measurements. Because of the need for reliable test equipment as part of any design effort, I applaud your magazine for the number of Product Features so far this year and the amount of detail provided in each. Many of your reviews seem like they are hands-on reviews, and your writers seem to have a good working knowledge of the test equipment and how it functions in different applications.

While many engineers would love to have the same test gear available at home for those weekend projects (although their spouses may not agree), the cost of most RF/microwave test equipment is too prohibitive for any kind of affordable home microwave test lab. Still, I remember when reading your magazine in the past when the price and availability (P&A) of each reviewed test instrument was listed at the end of the article. I would like to see your editors get back into this habit so that readers can at least have an idea of the price ballpark for some of the test equipment that is reviewed in each issue.

*H. Dolan*

## EDITOR'S NOTE

Your recommendation for listing P&A for each reviewed instrument and, possibly, for each product reviewed in each issue, is a good one. As for the "hands-on" nature of the test-equipment product reviews, many thanks are owed to the test-equipment companies willing to entertain visits from our editors when developing new products, and to company engineers and media professionals willing to even visit the magazine's editorial office with new equipment. Such visits offer *Microwaves & RF*'s editors the opportunity to "play" with new test equipment and get a handle on the important features beyond the specifications, such as the ease of use of a touchscreen display.

For many years now, our editors have been fortunate enough to be able to entertain some of the top T&M companies in the RF/microwave industry during the launch of a new test instrument, enabling them to prepare product reviews that are practical and useful to our readers. Our thanks to them.

*Jack Browne*
*Technical Contributor*

News

# QUALCOMM BRANCHES OUT AGAIN with Connected Car Platform

Qualcomm, the biggest maker of smartphone chips, has never disguised its ambitions to expand into new industries. The firm's new wireless platform is another step in that direction, allowing cars to connect with other vehicles, the cloud, and infrastructure like signs and traffic lights.

In the shadow of high-profile experiments with machine vision, automakers have been testing new wireless systems in their cars. The systems are supposed to be almost telepathic, enabling cars to spread alerts about an accident or tell other vehicles that they are making a sudden stop. The point, automakers and government officials say, is to alleviate traffic and make driving safer.

The Connected Car Reference Platform, which will become available in late 2016, is meant to serve as the nerve center for connected cars. It contains multiple wireless chips for handling all the data flowing into and out of vehicles. The device can support include cellular networks, Wi-Fi, satellite navigation, Bluetooth, and short-range protocols to share location data with nearby devices.

"It's like a Swiss Army knife," said Paul Sakamoto, chief operating officer at Savari, a Silicon Valley startup that plugged its connected vehicle software to the platform for a recent demonstration at the TU-Automotive conference in Detroit.

Using the platform's hardware, software developers can design custom applications, said Nakul Duggal, vice president of product management at Qualcomm. Tapping into the Wi-Fi chips, for instance, automakers could remotely update software in cars to close security glitches.

With all the progress in developing autonomous cars, many similar features are expected to become standard. In 2014, the European Commission agreed on standards for vehicles that "talk" with other cars and infrastructure. In the U.S., the Department of Transportation has said that a mandate for so-called vehicle-to-vehicle communications should be in place before President Barack Obama leaves office in 2017.

The new platform is the latest attempt to change course at Qualcomm, whose business has revolved around mobile processors and cellular modem chips. Over the last two years, facing the prospect of slowing growth in the smartphone market, the company has been aggressive in making new versions of its smartphone chips for robotics, servers, and wearables.

But rethinking the business is not coming easy. The company is in the middle of a larger

*(continued on page 26)*

**Large automakers, including General Motors and Ford, are not only testing machine vision systems but are also working to connect their vehicles with the cloud and other cars on the road. Qualcomm's latest platform is trying to make those connected cars easier to develop.** *(Image courtesy of Ford)*

## **FINDING THE RIGHT BALANCE** of Full-Duplex and Half-Duplex Radios

**FULL-DUPLEX RADIOS,** which can transmit and receive signals on the same frequency at the same time, have benefits that read like the bottles of snake oil. They can instantly double the data capacity of cellular networks, and allow smartphones and tablets to upload and download things like videos simultaneously.

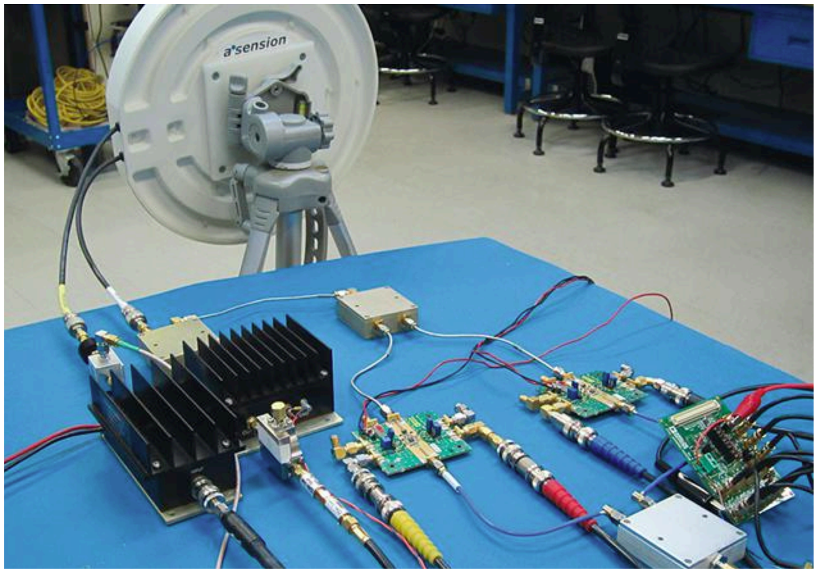
But the fine print warns of dangerous side effects. These radios have a tendency to absorb echoing signals from the transmitter, vastly increasing the amount of interference in the network. That, however, is not an issue for half-duplex radios, the hardware used in most cellular base stations and cell phones, which only send signals in one direction at any given time.

The interference problem has limited the market for full-duplex radios, but half-duplex radios are struggling with their own demons. These systems provide only half the spectral efficiency of their counterparts, a fact that has spread concerns about a wireless spectrum shortage.

Now, an engineering team from New York University and Ireland's Trinity College has discovered how to extract some of the benefits from both radios. The plan is perhaps unique in its simplicity: build cellular base stations with both full-duplex and half-duplex radios.

The idea, which was presented at the International Conference on Communications in Malaysia last month, is to equip small cells with both radios and then activate them depending on the situation. Allowing wireless carriers to switch between different configurations provides trade-offs in network capacity and coverage, the research team said.

Headed by Shivendra Panwar, an electrical engineering professor at NYU, the team found that setting up the cellular network with more full-duplex radios would provide greater capacity, while dropping more calls because of interference. When the base station used more half-duplex radios, the opposite was true: lower capacity, but more reliable connections to the network.



*A team from New York University and Ireland's Trinity College plans to build cellular base stations with both full-duplex and half-duplex radios. (Image courtesy of NYU Tandon School of*

> **"The interference problem has limited the market for full-duplex radios, but half-duplex radios are struggling with their own demons."**

"The beauty of this system is that it's tunable and would allow providers to adjust the mix of cells based on the needs of a region," said Sanjay Goyal, a doctoral student at NYU who helped author the paper. The spectral efficiency of full-duplex radios might be more useful in cities with crowded airwaves, he said.

"If you're designing an urban network, the demand for bandwidth is much greater than the need for wide-area coverage," he said. "More full-duplex cells would provide that bandwidth, even at the cost of a few more dropped calls."

Along with Professor Nicola Marchetti and doctoral student Carlo Galiotto, the engineers tested the hybrid system in modeling software, which uses algorithms to show how each radio configuration performed. The tests were carried out with virtual cell phones and tablets that contained half-duplex radios and antennas. Full-duplex radios were not used because they are too expensive and complex for consumer devices, they said.

While the mixed system could work for consumer devices, it will probably not find support for connecting infrastructure, like traffic lights and cars, or emergency response teams that are increasingly dependent on wireless service to get to victims faster. In those cases, the reliability of half-duplex radios could be more important that greater capacity.

The interference within full-duplex radios is the result of its tendency for signals to echo into the receiver when the system is in operation. That echoing can be vastly more invasive than external signals wafting into the receiver from other transmitters.

Mitigating that interference has been at the heart of recent research into full-duplex radios. Earlier this year, engineers at Columbia University built a full-duplex radio that could transmit and receive signals through the same antenna simultaneously, while suppressing the noisy echoes with a special filter-like device.

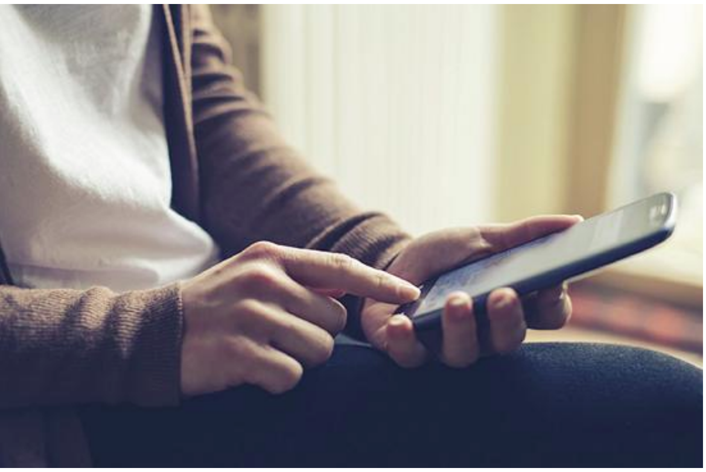
Panwar uses the metaphor of people

trying to talk and listen at the same time to describe the limitations of full duplex. "Even if you were capable of speaking and listening at the same time, everyone around you would be doing the same thing," he said. "It would be impossible to tune out that extra noise, and the same is true in a full-duplex system. There are many more outages and dropped calls due to the high level of interference."

Half-duplex radios abide by completely different rules, splitting transmit and receive duties. That can be carried out in two ways. The first is frequency-division duplex, in which transmission and reception are split into separate frequencies, so that the signals cannot bleed into one another to cause interference. The other way is with time-division duplex, a process that transmits and receives on the same frequency but staggers the times when they happen.

The research team also said that the mixed-duplex system could give carriers control over their download and upload speeds. Because download traffic far exceeds upload traffic on most networks, the carriers could potentially enable faster downloads while suppressing upload times, the team said. ■

## 4G FINALLY TAKES SEAT at Wireless Throne



*(Image courtesy of Thinkstock)*

**NEARLY SEVEN YEARS AGO,** TeliaSonera flicked the switch on the first commercial 4G LTE networks in Stockholm and Oslo. There were few mobile devices that could access these networks, and the event passed with little ceremony. But it was the first step on a journey to 4G supremacy.

Later this year, revenue from 4G services will overtake those from 3G operations for the first time, according to estimates from Strategy Analytics, a research firm that tracks global wireless revenue. The analysts expect that 4G LTE services will yield around $426 billion by the end of 2016, an increase of around 35% over last year.

It has been an ongoing process for wireless carriers and chipmakers to phase out older wireless technologies. Smartphones and other handheld devices still contain chips to access 2G and 3G networks, which were introduced in 1991 and 1999, respectively. The devices simply switch between networks depending on the radio equipment that covers the area.

These earlier generations are still widely used in developing countries in Africa, Asia, and the Middle East. According to research from Ericsson, a wireless networking equipment maker, 2G will remain the dominant form of cellular communication in these areas until around 2018.

In other places, these networks are reaching their shelf life. Major wireless carriers in the United States and South Korea are in the process of shutting down 2G service and recycling the spectrum for newer networks. In 2016, according to Strategy Analytics, service revenue for 2G is expected to decline 21%, while revenue from 3G networks will fall 19%.

As older networks shut down, 4G is filling in the gaps. "The advanced markets of the U.S., Japan, and South Korea will see the vast majority of their revenue come from 4G LTE services this year," said Phil Kendall, an analyst with Strategy Analytics.

Kendall estimated that, in 2016, around 79% of service revenue in North America would be linked to 4G networks. That compares to 82% in Japan and 90% in South Korea, while the Middle East and Africa would only have about 10%.

China is no slouch in this respect, even though 4G accounts for only about half of its enormous cellular revenue. In late 2015, China overtook the United States as the largest market for 4G networks, according to Strategy Analytics, thanks to its vast smartphone market and the large chunk of its population living in cities. ■

## CARLISLE INTERCONNECTS Buys Cable Maker Micro-Coax

**CARLISLE RECENTLY AGREED TO** acquire Micro-Coax, one of the biggest makers of coaxial cable for transmitting high-frequency radio signals. The company will become part of Carlisle Interconnect Technologies, the business unit that produces wiring and connectors for microwave applications.

The deal unites two companies with very similar product lines. Both make shielded wire and coaxial cable, in addition to other parts like connectors and contacts. These products are primarily used to connect radio transmitters and receivers with antennas inside military electronics, satellites, automated factory systems, airplanes, test equipment, and medical devices.

*(Image courtesy of Thinkstock)*

The terms of the deal were not disclosed. Carlisle also acquired one of Micro-Coax's business units, Kroll Technologies, which provides electro-plating services and fabricates extremely small metal parts for a wide range of industries.

Based in Pennsylvania, Micro-Coax has long been a major supplier of semi-rigid coaxial cable, a special type of transmission line that severely limits the power lost when signals pour into cables. Semi-rigid cables have "the advantage of the smallest possible diameter, nearly 100% isolation, and near-theoretical textbook attenuation," said Chris Kneizys, Micro-Coax's CEO, in a 2015 interview with *Microwaves & RF*.

While both companies make overlapping products, the scale of their operations are worlds apart. Carlisle Interconnect Technologies, which is organized under a holding company, generated revenues of $196.7 million in the first quarter of 2016, according to government filings. That represents nearly a fourth of the holding company's total revenue for the quarter.

Micro-Coax, a privately-held firm, only had annual revenues around $45 million, according to a Carlisle statement. Though small, the company was in the process of expanding before the deal. Last month, Micro-Coax began growing its staff (now standing at 235), hiring for positions in manufacturing and engineering to help transition into new markets.

Micro-Coax was founded in 1962. A.H. Mainwaring, the engineer that invented the precursor to semi-rigid cables, established the company as a business unit of his first company, Uniform Tubes. The firm's first major achievement came the following year, with the design of gold jackets for the cabling inside the first Apollo spacecraft.

Over the next 50 years, the company expanded into delay lines, connectors, and specialized products for shielding electromagnetic interference. One such shielding technology, Aracon, is a yarn-like conductive fiber that can replace metal cable and conventional braided shielding in airplane electronics. Its natural and synthetic fibers are treated to conduct electricity, and the resulting yarn is stronger, lighter, and more flexible than metal wire.

"We are excited about the acquisition of Micro-Coax, as the company adds capabilities and technology to strengthen our interconnect products business in very attractive sectors," Chris Koch, Carlisle's chief executive, said in a statement. ■

*(continued from page 20)*

restructuring that could cut 15% of its workforce to reduce costs. Qualcomm has also been the target of anti-trust investigations in China, which hurt its massive licensing business there and could lead to further ramifications.

Thus far, however, the automotive business has been a bright spot. Qualcomm has sold over 340 million automotive chips, mostly for telematics (like hands-free calling and navigation systems) and infotainment (like Apple Car Play and dashboard texting). Earlier this year, the latest automotive version of the Snapdragon 820 chip was released with an integrated X12 LTE modem for things like video streaming, voice recognition, and real-time traffic updates.

Qualcomm is not without a wide audience for its latest platform. The number of startups developing software for automobiles has ballooned in recent years, as automakers companies strive to make their vehicles more like smartphones. Hortonworks, for instance, has adapted its software to gather certain types of data from the vehicle, including speed, location, and safety responses like airbag deployment. It stores that data in the cloud so that automakers can analyze it, supplementing data on everything from diagnostics to driving habits.

Another startup, Movimiento, has ported its technology to the platform for automatically updating car software. Using cellular networks to access the cloud, automakers can update things like the operating system in the dashboard display, or even the software that controls autonomous driving.

The platform can also support automated safety features and warnings. Savari provides technology for dedicated short range communications, a wireless standard that has been widely used to connect vehicles with their surroundings and other cars. This is known as Vehicle-to-X or V2X communications and Savari refers to it as sensor technology, similar in nature to the machine vision and radar sensors.

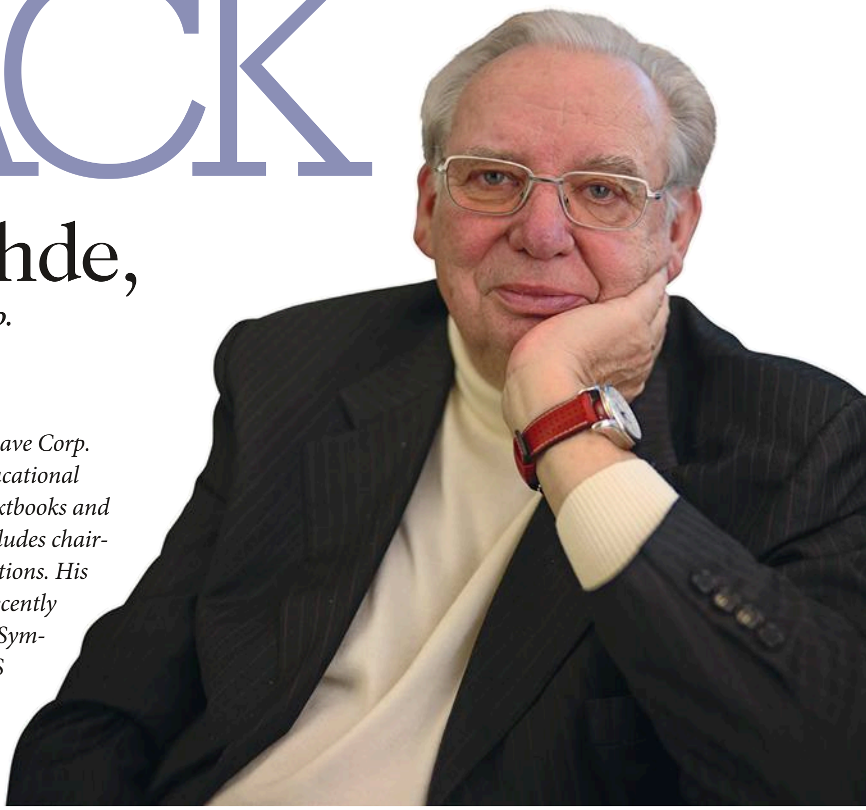
By sharing location data with other cars on the road, Savari's software can warn drivers of a possible collision. Even hardware in smartphones can be reprogrammed to share data over DSRC, letting cars know the location of people walking around with phones in their pockets.

It is like sensor technology that works out of the car's line of sight. "The big advantage of DSRC is that it's always sending information," said Savari's Sakamoto. "It's proactive. We are getting information ahead of obstacles on the road."

# Inside TRACK with Ulrich L. Rohde,

***Chairman, Synergy Microwave Corp.***

Interview by JACK BROWNE



*Dr. Ulrich Rohde, chairman of Synergy Microwave Corp. (www.synergymwave.com), is a major guiding educational force in the RF/microwave industry through his textbooks and extensive volunteer work with the IEEE, which includes chairing technical sessions and judging student competitions. His generous educational efforts were acknowledged recently by the IEEE at the 2016 International Microwave Symposium—he was given the prestigious 2016 MTT-S Microwave Application award. This is just one of the awards bestowed on Dr. Rohde by the IEEE over the years, along with, for example, the 2014 IEEE IFCS Sawyer Award and the 2015 IEEE IFCS Rabi Award.*

*His work on low-phase-noise oscillators and frequency synthesizers is well known in the industry and has often been covered by this magazine over the years. Dr. Rohde works closely with his wife, Meta, who is president of Synergy Microwave Corp. and manages the business end of the company, as well as with Synergy Chief Scientist Dr. Ajay Kumar Poddar on the technical direction of Synergy. Here are some highlights from our recent conversation with Dr. Rohde:*

**Your textbooks have served as engineering resources for many in this industry** *(for more on Rohde's texts, see "A Look at the Books" online at www.mwrf.com)*. **How do you find time to keep them up to date?**

**Rohde:** Given my advanced age, various sections in the books, such as the frequency synthesizer text with circuits based on discrete components, must be updated. I am in the process of working out arrangements with young professionals and scientists from the industry, and the publisher of the book, John Wiley & Sons, to update that book. This arrangement will allow me to still be involved with the quality of the text, but they will receive the royalties for their efforts in updating the book.

Updating is necessary because of the constant turnover of electronic parts. Say, for example, that you are working on a frequency-synthesizer design and you use an application note based on a certain set of components, and then they are no longer available. If no other available components are compatible, there is the difficulty of having to reproduce that synthesizer using other devices. The synthesizer textbook teaches engineers to think about what is really going on with these circuits and how to optimize the design. All of the mathematics required for designing synthesizers from scratch are in this book.

A critical component in many synthesizer designs is the transistor and many semiconductor manufacturers have stopped making discrete transistors for various reasons. And when they make a next-generation device, it may not have the same phase-noise characteristics as the previous-generation device. As a result, an oscillator or synthesizer design based on the original device must now be modified to achieve the same performance with the new device.

**Can younger engineers rely too much on software design tools? Should they spend some time learning the essential education in these books?**

**Rohde:** You should have both, with the appropriate textbooks to reinforce work performed on modern software tools.

**How long does it take to write one of these text books?**

**Rohde:** The first edition took 18 months. The book came out of my teaching at George Washington University. The graphics are the biggest problems for me, since I don't have the proper tools for creating schematic diagrams for these books. Nowadays, book publishers want you to provide camera-ready pages, and I simply don't have the means to properly generate the types of schematic diagrams and graphic files they would like.

**Synergy Microwave Corp. is well known for low-phase-noise oscillators and frequency synthesizers. Are there challenges in trying to measure such low levels of noise, as in having test equipment that is noisier than the sources you are trying to measure?**

**Rohde:** This is a political question. Around 1982, when I worked at RCA Laboratories, I developed an algorithm for signals that can find the carrier in the noise. Using correlation, I was able to regenerate a carrier from the noise. But this is a calculation, and not a measurement. Modern phase-noise equipment has been developed for this purpose, but it is important to separate what is measured from what is calculated. If you can show –190-dBc/Hz phase noise on an instrument display at 0-dBm input, this is not measured, this is calculated.

Mathematically, you can predict certain behavior, and you can calculate low levels of noise. You cannot measure below kTB. The Nyquist-Johnson noise power sets the limit that you can measure. That is your lower limit on noise measurement, where kT is –174 dBm. If it is a single sideband measurement, it is 3-dB less, or –177 dBm. This is the best you can measure, with another 3 dB, to reach a noise floor of –180 dBm. Mathematically, you can get an additional 10 dB by means of calculation to reach a noise floor of –190 dBm. But any levels shown by test equipment to be that low are not measured, they are calculated.

One of the problems with such calculated results is that crystal-oscillator manufacturers will claim to have oscillators that are capable of these incredibly low phase-noise numbers, but they are not real, they are not measured, and the oscillator cannot achieve those low levels. The best number you can measure is –177 dBm, which is single sideband. And that's really –174 dBm for double-sideband noise, plus another 3 dB for the active gain of the transistor in the crystal oscillator, to reach a limit dictated by physics of –180 dBm for single-sideband noise. These are the limits of physics, but no one has ever published this in these terms.

**Has today's test equipment reached an upper limit on performance, or is there room for improvement?**

**Rohde:** It depends on what you want to measure. As far as cellular telephones, which are the largest market for high-frequency test equipment, some companies test everything, while some only test about 10% of their products.

Many people are now talking about the fifth generation (5G) of cellular radio, but the standard is not defined yet. So how can you build test equipment for a standard that is not yet defined? The way out of this is to take a vector signal generator and an arbitrary waveform generator and mix them together with in-phase (I) and quadrature (Q) signal-generation capability. Therefore, with these three techniques, you can essentially generate each and every waveform that you want and whatever will eventually be part of the 5G standards.

In terms of phase-noise measurements, there is a lot of "hocus pocus" in the industry regarding the way that different instruments measure phase noise. These instruments have a lot of intelligence and it can get tricky to use them when you program them incorrectly. You can get almost any number, although it may not be the correct answer. Ajay has a paper that we published where there is a fair comparison about the results of who does what in the market for phase-noise measurements.

We have phase-noise measurement equipment from a number of manufacturers. So if someone wants to compare measurements they made, for example, on an instrument from one particular manufacturer, whether it be from, say, Keysight Technologies or Rohde & Schwarz, we have the same equipment in-house and can compare measurements. I think this is politically and practically important to some customers to show that I am not playing any games.

Currently, I am supervising several PhD dissertations. One of them is on crystal oscillators. As of today, Wenzel has the world-leading crystal oscillators, and they may believe that we are in volume production of crystal oscillators, but we are not. We don't have the facilities or the capabilities for that. Rumor has it that they are more irritated than fearful of us.

We built some systems in-house where we needed specific crystal-oscillator requirements. For the few pieces we needed, they would charge too much. So, it is better we develop these things ourselves. We indicate that we have them if someone wants them, but we are not in the business of making and selling crystal oscillators. That is an important message to the industry. If you do it right, you have to make a few hundred pieces per week or something like that. We simply don't have the facility or the number of people or the burn-in ovens and other equipment needed to do this. I am not a threat to anyone in the crystal-oscillator marketplace.

**You work at Synergy with your wife, Meta, and a very talented chief scientist, Ajay Kumar Poddar. When**

**a customer brings a new problem, do you consider it separately or do you look at it as a team?**

**Rohde:** Ajay's educational background in mathematics is better than mine. He is much better educated in advanced mathematics than I have had the opportunity during my university time decades ago. In some areas, I have more practical experience. So, we pool our knowledge.

My wife, Meta, handles the business side of things at Synergy, and she comes into play because the customer is also concerned with cost. A customer may need an oscillator with a certain set of requirements, so it is necessary to take a parts count and see what needs to be in the design to make this possible.

Let's assume that the parts count comes to a total of $200,000 for the bill of materials (BOM). You have to assemble it, test it, sell it to a distributor—you have all kinds of costs associated with it. You need a factor of three to four above the BOM and then, if you are lucky, you might make 20% profit after everything is said and done. There is a market price and there is a production price, and there are certain designs where even for a small company, it is not possible to produce something for any kind of reasonable margin.

What is fascinating is that the customer may then lower their specifications. Then, our advantage of having a superior product is gone because with 10-dB worse performance compared to the original specifications, everyone can do it. So it is not always a blessing to be the best at something. Sometimes you lose in spite of better performance.

As a team, my wife and the people who manufacture these things in house have an equal say in what we do. Ajay and I can define the architecture, and what is in it and what is possible, but this is not necessarily the part that earns the business. The winning part is not to leave money on the table. Some of my competitors are so eager to get a particular order that they are selling below cost. We do not do this here. I would rather not have the order.

We have had this company since the 1980s. We have had good years, excellent years, and difficult years. But the important thing is that we have no liabilities. This company doesn't owe any money to any bank; everything is paid for. We have a stable war chest and don't need to report to anybody. There are no quarterly pressures. We have about $10 million worth of test equipment. We are not pressured by shareholders. If you buy something from us, it's good. It has been tested and we know that it works.

**Synergy is in many different markets. Can the stability of the company be attributed to this market diversity?**

**Rohde:** We also help some other companies. There have been cases where some well-known companies couldn't measure something. We had defense companies and these other customers come to us. As you can see, we are well-equipped with test equipment, and we have our own Faraday cage for particularly sensitive and difficult measurements.

We have been able to measure some things that other people could not because they couldn't afford some of this equipment. As a result, these defense companies now come to us, noting that we are so well-equipped and so capable. This actually helped us by helping other companies, getting business by helping these companies. There is very little that we cannot measure. We are equipped to measure up to 120 GHz. Not everybody can do this.

**Our industry likes to switch technologies and "falls in love" with the latest great thing, like gallium nitride (GaN). Does this switching of technologies, such as from silicon bipolar to GaAs to GaN, pose a problem for you, whereby something might become obsolete?**

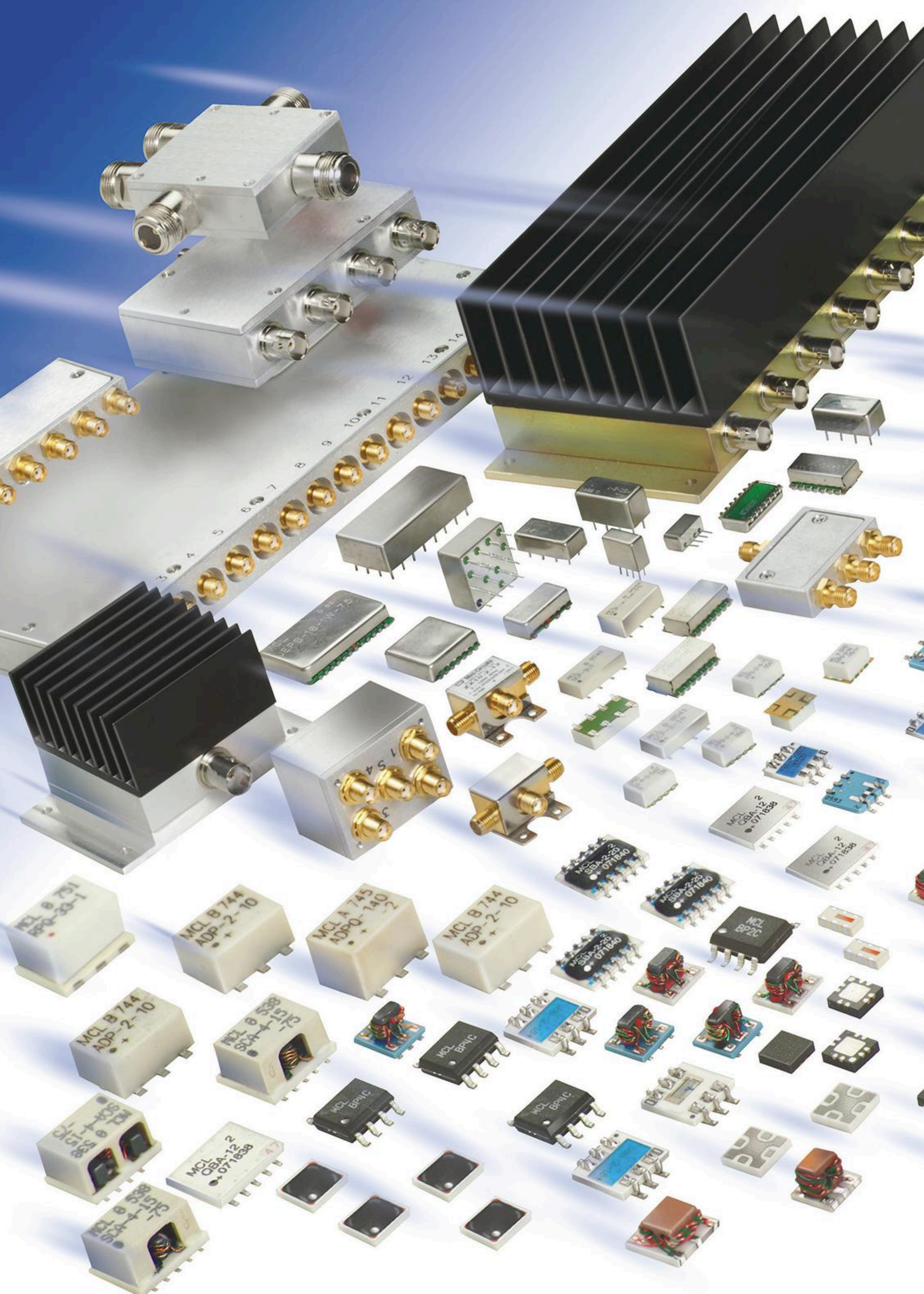
**Rohde:** Gallium nitride is for power transistors. GaN has excellent thermal conductivity, so it can get rid of the heat better than some other semiconductor materials. And it can run at higher voltages. By itself, it can make a nice device. The flicker corner frequency of these things is fairly high.

If you take smallest device you can find, and use it as a low-noise preamplifier, the nice thing about it is that it can withstand high pulses. A typical radar system of conventional design needs a limiter, so you have to have a few diodes up front. Therefore, if you have a strong signal in your antenna, it can burn out your preamplifier. But by using a GaN preamplifier, it is almost indestructible. With GaN, you can eliminate these limiters, and the circuit design thus becomes easier.

I am not in this area, but I wish someone would make a low-noise GaN preamplifier for 10-mW or maybe 100-mW output power to help simplify the radar design. I don't think low-power GaN devices will be going anywhere anytime soon, and there will not be any immediate successors to GaN. So I would like to see someone come up with a really low-noise preamplifier based on GaN.

**Synergy is well known for "pushing the limits" in terms of technology advances, certainly in phase noise. Are you involved in any other development projects?**

**Rohde:** We are well aware of the need for conversation of energy, and are involved in next-generation energy-saving electronic circuits and systems based on energy-harvesting techniques. We are exploring Möbius technology for sensor applications, too, as well as negative-index Möbius technology for use in 5G wireless systems and for Internet of Things (IoT) applications. In connection with expected requirements for 5G and IoT, we are also investigating RF microelectromechanical-systems (MEMS) components incorporating repulsive Casimir effect approaches for improved switching performance. In addition, we are studying anti-gravity technology based on negative-index material and thermally stable, tunable, optoelectronic oscillator circuits to 500 GHz for terahertz and other applications. mw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# TRANSMITTER ARRAY
## HELPS DETECT GAS AT 245 GHz

TERAHERTZ FREQUENCIES ARE becoming more achievable with improvements in semiconductor materials and processing. Such high frequencies have tremendous benefits for medical treatments and in different types of sensors, such as gas sensors. To offer a hint of some of the uses for higher-frequency signals, researchers from several German institutions, including IHP, developed a transmitter array based on silicon-germanium (SiGe) BiCMOS semiconductor technology. The function blocks included a transmitter, receiver, and a gas Golay absorption cell fabricated in 0.13-µm BiCMOS with SiGe:C heterojunction bipolar transistors (HBTs) characterized by transition frequency of 300 GHz and maximum frequency of oscillation of 500 GHz.

The transmitter array was designed with four transmitters for spatial power combining. Each includes a two-stage power amplifier, a frequency doubler, and an integrated antenna. The inputs of the transmitters are connected to a Wilkinson power divider, which is fed by a local oscillator (LO). The LO is a 120-GHz voltage-controlled oscillator (VCO) and 1/64 frequency divider with two-stage differential amplifier and external phase-locked loop (PLL). The companion antenna array integrates with the transmitters by means of microstrip interconnections on a silicon substrate.

A commercial test receiver was used to measure the signal levels from the transmitter array, and the estimated gain based on measurements was 6 dBi at 245 GHz. See "245-GHz Transmitter Array in SiGe BiCMOS for Gas Spectroscopy," *IEEE Transactions on Terahertz Science and Technology*, Vol. 6, No. 2, March 2016, p. 318.

## NOVEL MODULATION APPROACH SHRINKS
# KA-BAND RADAR

RADAR SYSTEMS ARE employed in far more applications than "just" on the battlefield. Modern weather forecasts, for example, are based on commercial weather radar systems, while many modern automotive collision-avoidance systems are now based on millimeter-wave radar systems. Implementing such systems in practical and affordable solutions, however, has long proven challenging for high-frequency system engineers; the size and costs of components required to achieve the wideband in-phase/quadrature (I/Q) modulation in such systems are prohibitive. Fortunately, researchers at Caltech, involved in design work for NASA's Jet Propulsion Laboratory (JPL), developed a novel modulation scheme for a Ka-band precipitation profiling radar system. This approach makes it possible to significantly shrink the size of the system compared to conventional designs.

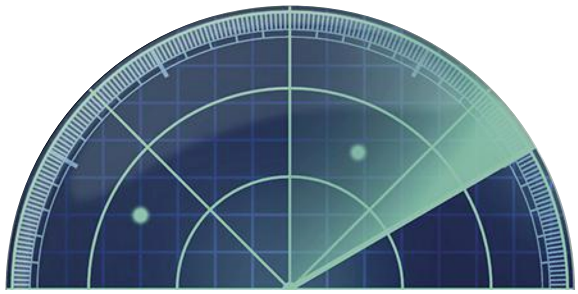
The modulation scheme uses pulse compression and direct I/Q upconversion to overcome some classic problems of I/Q mixers, both in terms of gain and phase imbalances between channels, and leakage of the local-oscillator (LO) signals required for frequency upconversion from baseband modulated signals. By adopting a direct-conversion architecture, the new approach reduces the components required in the radar system. Through optimum selection of transmit signals and digital signal processing, the system minimizes sensitivity to LO leakage and image generation. The system is able to achieve high-purity signals with exceptional side-lobe suppression. See "Offset IQ Modulation Technique for Miniaturized Radar Electronics," *NASA Tech Briefs*, April 2016, p. 36.

# MEANDER-LINE DIPOLE SERVES SMART SENSORS

INCREASING USE OF smart meters and Internet of Things (IoT) devices will erode limited bandwidth. Lower-frequency bands at 450 MHz are available for smart-metering applications, but lower frequencies imply larger wavelengths and larger antennas; these may not always be compatible with meters and sensors designed to be inconspicuous. To provide a solution, researchers/designers from different organizations in Dublin, Ireland proposed a folded meandering monopole antenna capable of receiving signals within the 410- to 470-MHz UHF range. The antenna is printed on low-cost, double-sided FR-4 printed-circuit-board (PCB) material. The antenna is located on the corner of a rectangular ground plane measuring 130 × 70 mm.

The compact UHF antenna design was fabricated, tested, and simulated with commercial simulation software. The movable aluminum via slider, which controls the resonant frequency, allows tuning at any frequency across the frequency range. The antenna design provides a tunable bandwidth of 409.5 to 481.1 MHz,. The antenna was simulated alone and as an installed component of a system, using different orientations of the antenna ground plane in the models. Although there was some shift in center frequency as a result of the change in ground-plane orientation, the omnidirectional antenna provides a stable radiation pattern across its tunable bandwidth with measured efficiency of 21%. See "Folded Meandered Monopole for Emerging Smart Metering and M2M Applications in the Lower UHF Band," *IEEE Antennas & Propagation Magazine*, Vol. 58, No. 2 April 2016, p. 60.

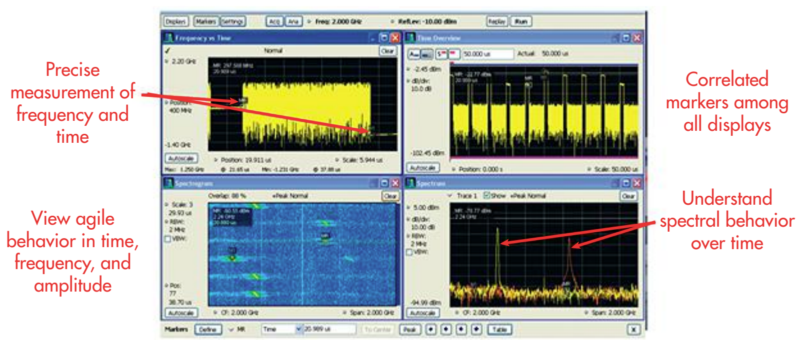
CHRIS DeMARTINO | Technology Editor



# RADAR TECHNOLOGY Encroaches Upon New Territories

**As radar systems utilize more advanced technology, companies must respond with the simulation and test products needed to both design and test modern radar systems.**

Radar technology has grown in complexity, with a number of advanced techniques now being utilized. For example, complex modulation schemes have found their way into radar applications. These techniques and others have prompted suppliers of test-and-measurement equipment to deliver products to satisfy today's radar test requirements. With recent innovations in test, as well as simulation, radar is quickly advancing to provide heightened capabilities and advanced features.




**1. SignalVu software provides a solution for frequency-hopping testing.** *(Courtesy of Tektronix)*

## RADAR TEST SOLUTIONS

Suppliers of test-and-measurement equipment must provide the tools to satisfy today's radar test needs. One company that offers both hardware and software solutions to meet these challenges is Tektronix (www.tek.com). "Radar-system designers are turning to techniques such as ever-more complex modulation, pulse compression, and frequency-hopping schemes—all of which place significant requirements on the test equipment used to design, test, and characterize these complex systems," says David Taylor, a technical marketing manager with the firm.

"To meet modern radar and electronic-warfare (EW) test challenges," adds Taylor, "test solutions must provide simultaneous, multi-domain operation, combining sophisticated signal detection, acquisition, and analysis capabilities in the time, frequency, and modulation domains. Test solutions must also be capable of generating complex high-bandwidth signals so designers can test systems under more realistic conditions."

Meeting current radar test requirements involves more than just hardware. Software is also counted on to analyze and test today's radar systems. "Increasingly, modern wideband and frequency-hopping radar systems require the use of automated analysis and visualization software solutions," says Taylor. "With the growing complexity, automated measurement solutions have migrated from being a convenient time-saver to becoming a fundamental requirement for successful radar system design. One example is trend analysis that can involve dozens of pulse parameter measurements on thousands of pulses—it's simply not feasible to setup and perform these measurements manually."

Radar designers can take advantage of a variety of tools from Tektronix. "For signal-generation needs, our arbitrary


**2. This radar target simulator can operate to 40 GHz.** *(Courtesy of Eastern OptX)*

The Series 1100 can cover frequencies as high as 40 GHz while achieving greater than 100 dB of dynamic range. It operates with pulsed, frequency-hopping, or CW radars, with any encryption or modulation scheme. Target distances can range from 1 to 100,000 meters. Furthermore, the Series 1100 radar target simulator offers expandable range and operation modes to accommodate new system designs. Applications for these test systems include phased-array radar systems, tracking and surveillance, and more.

waveform generators (AWGs) offer extremely wide modulation bandwidth and deep memory combined with comprehensive waveform generation software," continues Taylor. "Our spectrum analyzers offer simultaneous multi-domain operation combined with high dynamic range. These are combined with oscilloscope-based solutions with up to 70-GHz bandwidth for capturing the widest RF events. And with the addition of SignalVu software *(Fig. 1)*, we provide a common vector-signal-analysis (VSA) user interface and feature set across all our instruments."

## RADAR TARGET SIMULATION

By utilizing a radar target simulator, radar designers and system test engineers can create full simulations of moving targets. Such capability is achieved by the new Series 1100 radar target simulator *(Fig. 2)* from Eastern OptX (www.eastern-optx.com). The Series 1100 receives a transmitted signal from a radar system and adds the round-trip propagation delay associated with the target distance. Next, that signal is output to the radar receiver. The radar input/output (I/O) can be connected directly to the Series 1100 or, alternately, user-specified antennas can be utilized for receiving and transmitting. For a moving target, the system will add the appropriate Doppler shift associated with the target speed and radar frequency.

"The problem that radar-system test engineers have is reproducing targets as they would appear in the real world," says Joe Mazzochette, general manager at Eastern OptX. "There are a number of ways to create these targets with electronic simulations. However, our approach is to re-create the propagation path that the radar system would see in the real world.

"The test system must be capable of responding very quickly so it can reproduce fast targets with high refresh rates," adds Mazzochette. "Of course, it has to be accurate. And it has to be capable of accommodating any sort of radar signal format, including pulse, continuous-wave (CW), frequency-agile, and adaptive systems. The Series 1100 test system is a single turnkey box that can be programmed to re-create simulations with very high refresh rates. It can re-create very-high-speed targets (or even very-low-speed targets)—anything from an animal crawling along the ground to the replication of a mortar fire."

## DESIGN SOFTWARE FOR RADAR SYSTEMS

Designing a radar system can be challenging because it involves the analog, digital, and RF domains. A complete system covers everything from the antenna array to radar signal-processing algorithms. As a result, there is a need for modeling and simulation software at different phases of the development cycle.

"Radar technology advancement is one of many trends that we expect will encourage component- and system-level designers to rethink their approach to new product development," says Ken Karnofsky, senior strategist for signal-processing applications at MathWorks (www.mathworks.com). "From a designer's perspective, radar requires expertise across different engineering areas. These areas include digital signal processing (DSP), RF, and antenna design—a collection of skills that a single engineer rarely possesses. Rather, these complementary talents require underlying modeling, multi-domain simulation, and prototyping tools that provide a commonly understood development platform, in order to enable a clean handoff at each stage of the design workflow—regardless of the engineer's specific role."

MathWorks is fostering radar-system design with a collection of tools that includes MATLAB and Simulink, as well as the Phased Array System and Antenna Toolboxes. "Using certain design tools, such as algorithm development software, will help to bridge the technical divide and accelerate the use of simulation and rapid-prototyping environments to enable today's design teams to work more efficiently and effectively," notes Karnofsky. "Companies like MathWorks must match these rising expectations placed on engineering teams with well-integrated design tools. These tools must enable rapid, efficient prototyping, and yield code that can then be implemented at both the conceptual and production phases of product design."

To summarize, it is clear that radar technology has significantly increased in complexity. In response, companies are providing cutting-edge design and test solutions to meet these advanced demands. Expect to see suppliers of design and test products continue to rise to the occasion to meet the needs of current and future radar technology.

JACK BROWNE | Technical Contributor

# Making Optimal Coaxial Connections

**Coaxial cable assemblies must route high-frequency signals through many shapes and diameters, all the while maintaining signal integrity and minimizing losses.**

**COAXIAL CABLE ASSEMBLIES** fit many applications, from connecting signals generated by antennas to receivers and transmitters in communications systems, to transferring signals in test systems. No single cable assembly type fills all requirements, especially with the plethora of connectors and frequency bands in use in RF/microwave applications.

Although they require mechanical mating at input and output ports, the best coaxial cable assemblies are electrically invisible, with minimal degradation of signal amplitude and phase. Choosing a cable assembly, as with many high-frequency components, usually comes down to price, performance, and durability—especially for cables expected to have long lifetimes.

Cable assemblies (*see figure*) can be rigid or flexible, enabling them to be used both for applications that require no bending and those that call for some (or possibly many) flexures. Some cables, such as those that are part of an automatic-test-equipment (ATE) system, may need to undergo thousands of flexures, ideally with minimal changes in amplitude and phase responses versus frequency.

Some cables, such as semirigid cables, provide a limited amount of flexure for making connections in a specific configuration. Other cable assemblies, such as those based on hand-formable cables, can be flexed numerous times, bent into a required shape, and hold that shape until bent again.

Coaxial cable assemblies generally consist of several components, including input and output connectors (not necessarily the same type of connector); inner and outer conductors; a dielectric insulating layer between the conductors; a conducting shield to minimize electromagnetic interference (EMI) and radio-frequency interference (RFI); and possibly a nonconducting shield around the outer conductor for environmental protection.

Stranded center conductors are used for maximum flexibility. When less flexibility is required, higher performance (less loss) can be achieved with a solid wire center conductor based on conductive metals such as bare copper or copper-clad aluminum. To minimize loss at higher frequencies, silver-plated copper wire (SPCW) or silver-plated copper-clad steel center conductors may be used.

**Coaxial cable assemblies are available in many diameters and connector terminations for applications from RF through past 110 GHz.** *(Photo courtesy of Times Microwave Systems)*

Flexible cables are noted for their ease of installation, especially for tight connections, but they have their drawbacks. One involves flexible cables that use a braided shield. Since it is not a smooth surface, bending can result in variations in the cable's electrical characteristics.

Variations can also result when bending cables with stranded inner conductors employed for maximum flexibility. Such electrical variations with bending can be minimized by using a solid conductor with a coating that smooths surface imperfections, or the use of a film shield within a braided shield, at a cost of loss of flexibility.

As with any RF/microwave electronic component, coaxial cable assemblies are characterized and compared by a set of electrical, mechanical, and environmental specifications. Since many variables are involved in the construction of a coaxial cable assembly—e.g., length, connector types, diameter, power-handling capabilities, and operating-temperature range—some cable suppliers provide online support in the form of cable-assembly guides.

W.L. Gore & Associates (www.gore.com) offers an RF/microwave cable-assembly calculator that prompts a user to enter requirements for frequency range, length, operating temperature, and even maximum altitude. Cables will then be configured with various diameters of solid or stranded conductors for applications through 67 GHz. The firm also supplies the Gore PHASEFLEX line of test cable assemblies, which operate to 110 GHz.

In addition, long-time cable supplier Micro-Coax (www.micro-coax.com) features a handy insertion-loss calculator on its website. It allows specifiers to assemble a cable assembly with desired input and output connector types and choice of coaxial cable. A user can then precisely determine the insertion loss (in dB for a given frequency) of the cable assembly, as well as the attenuation (in dB/100 ft) for a particular frequency of interest.

Some cable requirements are quite simple and may even tolerate some amount of loss over the operating-frequency range. Essential electrical characteristics include maximum operating frequency, impedance (typically 50 or 75 Ω), insertion loss, return loss or VSWR, shielding effectiveness (SE), power-handling capability, minimum bend radius, and operating-temperature range.

A cable assembly with a small minimum bend radius, for example, may allow a flexible or hand-formable cable to complete an interconnection in a tight place. On the other hand, a cable assembly not capable of the small bend radius would not be able to be formed into the configuration that is required for a tight interconnection.

Just how small a minimum bend radius for a flexible or hand-formable cable should be will depend on a particular application. For space-related applications, NASA has recommended (per NASA-STD-8739.4, 7.3.21) that the optimal bend radius of a single, flexible coaxial cable should be 10 times the diameter of the cable, or six times the diameter of the cable when forming and integrating the cable assembly into a system. Forming mandrels are usually advised when making an extremely tight bend radius. Some cable suppliers, such as Huber + Suhner (www.hubersuhner.com) with their 65-GHz-capable Minibend cables, can achieve a bend radius as small as 0.06 in.

Some applications, such as in test systems, may require that performance is evaluated as a function of flexure or time—for instance, changes in amplitude response over frequency with flexure and changes in phase response with frequency as a result of flexure. In some cases, the instance of flexure may occur only occasionally, such as when making connections to different test fixtures. Other applications may involve continuous flexure, such as when a device under test (DUT) is being constantly shifted during measurements (e.g., antenna radiation pattern testing).

Suppliers of flexible cables for test applications typically develop methods for evaluating their cables and cable assemblies both in static and dynamic cases. For example, Mini-Circuits (www.minicircuits.com) supplies CBL Series test cables for use in laboratory environments with the understanding that the cables will undergo some amount of bending with normal use.

To characterize changes in performance with flexure, the company developed a test technique in which various bend radii are applied to a 3-ft. cable assembly, and the changes in insertion loss, insertion phase, and VSWR are measured and normalized to the performance at a reference position for the same cable assembly. The CBL test cables are characterized for repeatable performance for as many as 20,000 flexure cycles per cable.

While no standards exist for coaxial test cable assemblies for amplitude and phase stability with flexure, amplitude stability of ±0.5 dB and phase stability of ±2 deg. would be adequate for most test applications. Of course, both parameters will be highly dependent on frequency, with high stability more difficult to achieve at higher frequencies.

Such cable-assembly characteristics are critical in test applications, because cables become part of the test system and can contribute to the measurement error of a vector network analyzer (VNA) that is being used to measure the amplitude and phase responses of other microwave components. For critical test applications, such as with VNAs, cable assemblies can be specified as phase-matched sets and with absolute or relative time-delay matching for two or more cable assemblies.

Cables assemblies are available with right-angle connectors and blind-mate connectors to simplify installation, typically at frequencies to 18 GHz, while rugged, larger connectors, such as BNC and Type N connectors, may be better suited for lower-frequency applications. As a starting point, the frequency range will determine much of the construction details of a coaxial cable assembly, including the connector options for a given high-end frequency.

As frequencies increase to the millimeter-wave range, available connectors shrink, which diminishes the number of connector and cable options. Connector dimensions, such as those for 3.5- and 2.4-mm connectors, shrink as a function of wavelength and shrink with increasing frequencies.

In addition to operating temperature range—like the extreme range of −55 to +125°C—environmental factors that contribute to the selection of a cable assembly include humidity, shock and vibration, and altitude (for use in airborne systems). Ruggedized cables with armored jackets are also available for use in harsh conditions, as are space-qualified cables. The latter typically undergo thermal vacuum testing to qualify the cable assemblies for high-reliability applications, such as in space systems. mw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| CBL | All-purpose workhorse cables for highly-reliable, precision 50Ω measurement through 18 GHz | DC-18 | SMA, N |
| APC | Crush resistant armored cable construction for production floors where heavy machinery is used | DC-18 | N |
| ULC | Ultra-flexible construction, highly popular for lab and production test where tight bends are needed | DC-18 | SMA |
| FLC | Flexible construction and wideband coverage for point to point radios, SatCom Systems through K-Band, and more! | DC-26 | SMA |
| NEW! VNAC | Precision VNA cables for test and measurement equipment through 40 GHz | DC-40 | 2.92mm (M to F) |

* All models except VNAC-2R1-K+

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# Compact Radar Form Factors Accelerate Commercial Adoption

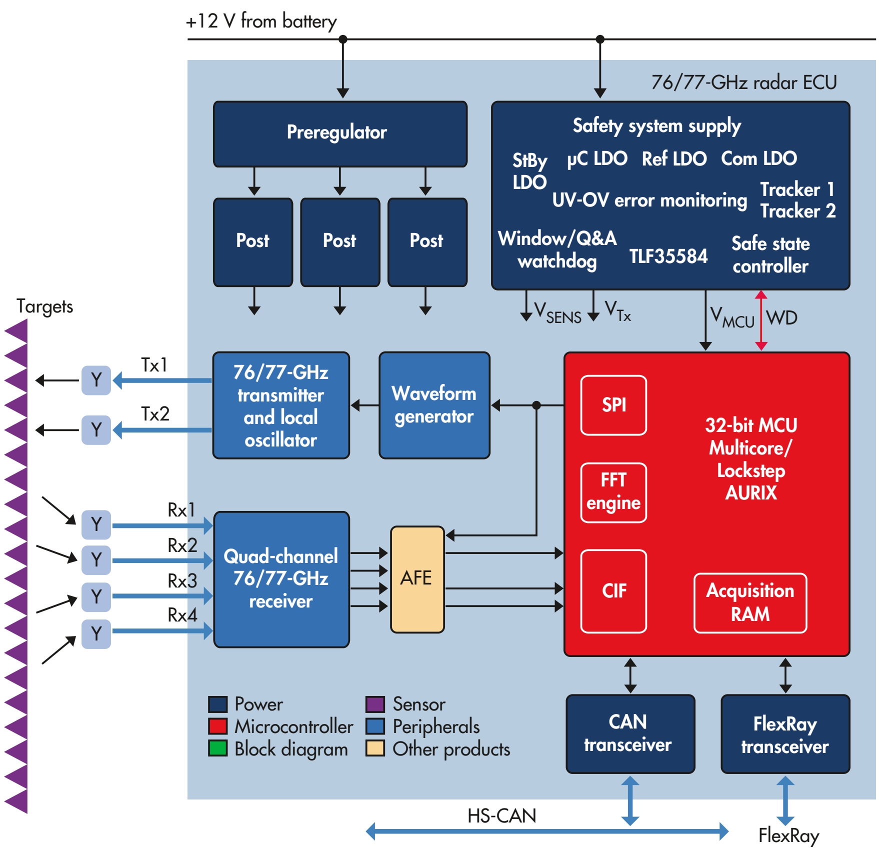
**Radar sensors are finding their way into more applications than ever thanks to technology advances that have reduced size and volume-production cost.**

**WITH CHIP-SCALE SYSTEMS** available both in microwave and millimeter-wave frequencies, commercial adoption of radar sensors for industrial, transportation, and consumer applications has sharply risen. In many ways, it is a familiar story of silicon integration, and we can see how issues such as form factor and power consumption are addressed in successive design iterations.

Most publicly recognized work in compact radar systems has centered on automotive applications. Introduced at the end of the 1990s as a premium feature in luxury cars, applications have evolved from warning systems to active driver assistance.

Installed in about 10% of vehicles on the road today, radar-based driver assistance is now commonly available in both high-end and mid-priced autos, and well on its way to becoming standard equipment. As the industry integrates autonomous driving functionality, it's expected that light vehicles will require at least five radar systems to provide 360-degree coverage for sense and control.

Across a large number of automotive applications, 77-GHz systems meet requirements for range (up to 250 meters) and the ability to accurately distinguish multiple objects. To provide high spatial resolution, 77-GHz-class systems actually utilize 4 GHz of bandwidth. Beginning in Europe in the early 2000s, regulatory bodies and industry harmonized on this fre-



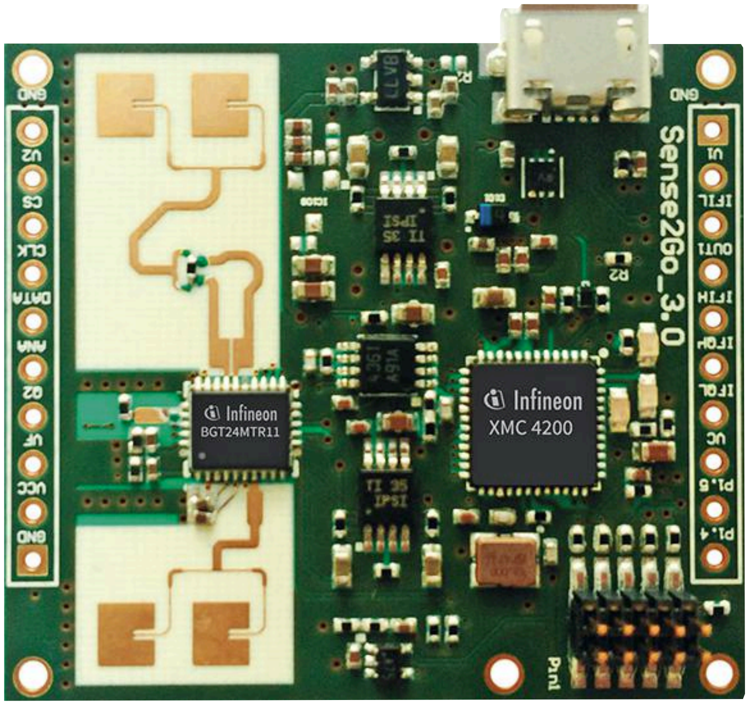

1. The ECU for a 77-GHz radar targeting ADAS systems has a higher level of complexity.

quency allocation, spurring market growth while allowing suppliers to develop signal propagation and antenna design expertise.

The cost curve for advanced-driver-assistance-system (ADAS) radars started arcing downward around 2008/9 in conjunction with the first commercial-scale production of fully automotive-qualified silicon-germanium (SiGe) integrated circuits (ICs) operating at 77 GHz. Previously the realm of gallium arsenide (GaAs), SiGe allows for higher integration, resulting in a two-chip (multichannel transmit and multichannel receive) sets replacing up to 8 GaAs chips.

The next step in this evolution was the ability to use embedded wafer-level ball-grid-array (eWLB) packaging, which was originally developed for consumer-electronics applications. Mass-production-friendly packaging lowered assembly cost for complete radar modules.

There's also the matter of the radar's electronic control unit (ECU), which has more complexity in order to meet required safety systems and design resilience for automotive operation (*Fig. 1*). However, it has both the precision and scalability from mid- to long-range operation to reach volume series production.




**2. Both the front-end and controller MCU squeeze onto Infineon's development board for 24-GHz radar.**

Today, 77-GHz class radar modules weighing in at about 200 g per module are implemented by several Tier One suppliers. These companies and the auto OEMs have gained the skills in beamforming and antenna-array design needed for accurate sensing of multiple objects at variable speeds and even different heights relative to the sensing vehicle. Operating power range is typically measured in low single-digit watts, well in line with the power requirements for both combustion and electric vehicles.

## SHORT- TO MID-RANGE FOR AUTOS AND BEYOND

In the mid- to short-range class of automotive radar applications (up to 100 meters), lower system cost may be achieved by implementing a 24-GHz design. Single-chip transceiver implementations (typically with dual transmit and receive channels) can be matched with additional receivers for the appropriate antenna schemes.

The reduced cost of microwave-frequency radar systems also makes the technology attractive in commercial-building automation applications. Previously the domain of passive-infrared (PIR) or even video systems, 24-GHz-band radar supports longer range detection, direction intelligence, and higher overall sensitivity at a relatively small cost premium. PIR sensors, on the other hand, have a relatively short range (about 10 meters); moreover, the sensor target must be moving, and there must be a significant difference between a target and the surrounding environment.

Used for presence detection in buildings, radar senses even non-moving objects (i.e., desk-bound workers) and avoids the tendency of PIR to turn off lights when people are sitting still. In an application such as automatic doors, radar provides longer range and can distinguish between passersby and people approaching the entrance. Available ICs with a single transmit channel and dual receive channels make it possible to calculate position, proximity, speed, and direction of movement. This creates a rich data set for radar-based security systems.

While continuously operating radar would most likely require line power, a duty-cycling technique can be used to

**RELATIONSHIPS BETWEEN SPEED, DOPPLER SHIFT, AND MEASUREMENT TIME**

| Speed (km/h) | 1 | 1.5 | 2 | 2.5 | 3 | 4 | 5 | 6 | 8 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| Doppler shift (Hz) | 44.4 | 66.7 | 88.9 | 111.1 | 133.3 | 177.8 | 222.2 | 266.7 | 355.6 | 444.4 |
| Minimum measurement time (ms) | 22.5 | 15.0 | 11.3 | 9.0 | 7.5 | 5.6 | 4.5 | 3.8 | 2.8 | 2.3 |

> "As the industry integrates autonomous driving functionality, it's expected that light vehicles will require at least five radar systems to provide 360-degree coverage for sense and control."

lower power requirements for battery-driven applications. The table denotes the Doppler shifts associated with various measured speeds, showing that a measurement period of about 10 ms enables accuracy to approximately 2.5 km/h. An update rate of 0.5 seconds can detect targets moving at up to 20 km/h—a rate that makes it easy to track a human or small animal. At this 0.5-second duty cycle, power consumption of the radar IC drops from 528 mW (using a 3.5-V supply) to just 12 mW.

With all circuitry for a radar sensor implemented in a single device, available 24-GHz transceivers eliminate the need to match external components and lay out RF transmission lines on the system printed-circuit board (PCB). This high level of integration can save up to 70% of the board area versus that of a discrete-based solution.

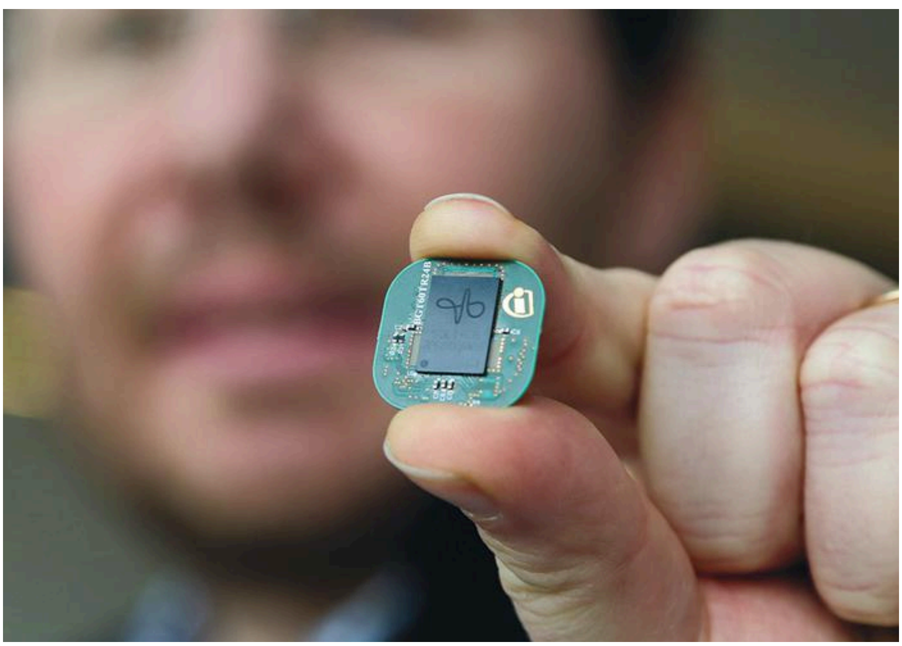
To illustrate potential system size, an Infineon-supplied development board (*Fig. 2*)—including both the radar front-end and controller MCU—measures just 4 × 3.5 cm. The board is useful for prototyping a compact radar sensor for domestic- or commercial-building automation applications.

### RADAR AT THE NEXT LEVEL

Recently announced details about Google's Soli radar project illustrate that 60-GHz mm-wave technology is near-ready for prime time in consumer applications. Soli represents a leapfrog in the current state of the art in terms of the packaged system size and power requirements.

As envisioned by engineers from both Google's Advanced Technology and Projects (ATAP) group and Infineon, the goal of the Soli project was a device control system that could be implemented across any type of CE product, with particular emphasis on devices with little or no "real estate" available for the human-machine interface. This meant a combination of miniaturization and reduction of power draw by orders of magnitude compared to existing devices. And this must be achieved at a price target that, while not disclosed as of yet, must be compatible with targeted consumer-electronics applications, such as smartwatches, gesture-controlled audio systems, and Internet of Things (IoT) devices.

A little more than one year ago, Infineon produced a 14-mm$^2$ development chip for release to application developers. However, it still required a standalone PC as a controller and drew 1.2 W during operation. Twelve months later, a new iteration of the IC measuring 12.5 mm$^2$ draws just 0.054 W and works with CE-class MCUs (*Fig. 3*). End-user systems are in development now, and the next wave of developers will gain access to the technology during Fall 2016.



3. The 12.5-mm$^2$ 60-GHz Soli radar-on-chip consumes a mere 0.054 W.

As we've seen, the growing ubiquity of radar is a tale of integration and the ability to implement RFICs in silicon processes. To this end, Infineon and other IC manufacturers are actively working to reduce the cost of radar sensors to extend the commercially viable price-performance ratio into broader markets.

Timetables for these programs indicate early commercial availability within the next year for millimeter-wave ICs. However, testing and deployment may take longer, as will ramping to scale. For the near term, and likely longer in the more rigorously qualified automotive and industrial segments, SiGe-based systems will probably be the preferred option for some time. mw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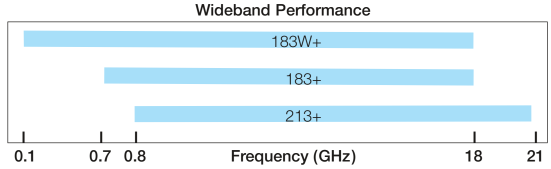
* Heat sink must be provided to limit base plate temperature. To order with heat sink, remove "X" from model number and add $50 to price.

Wideband Performance

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*National Instruments, Austin, TX 78759; e-mail: shivansh.chaudhary@ni.com*

SURESH OJHA | Principal Engineer
*National Instruments, Austin, TX 78759; e-mail: suresh.ojha@ni.com*

GAUTAM TALREJA | R&D Section Manager
*National Instruments, Austin, TX 78759; e-mail: gautam.talreja@ni.com, www.ni.com*

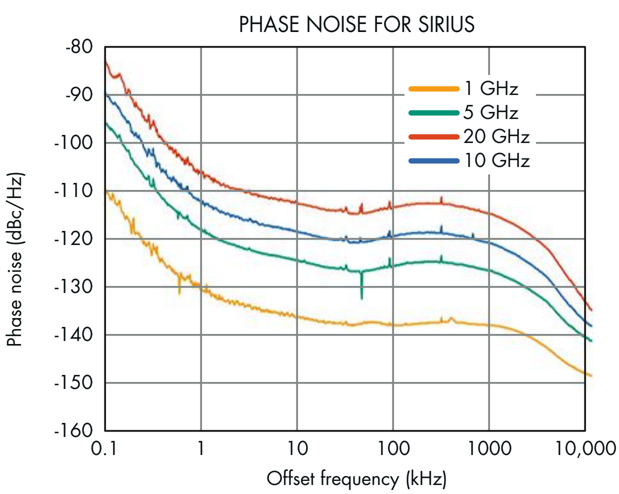
# Check the Specs When Selecting a Signal Generator

**During the process of choosing an instrument, it's wise to become keenly aware of key specifications in order to properly match it with a particular application's requirements.**

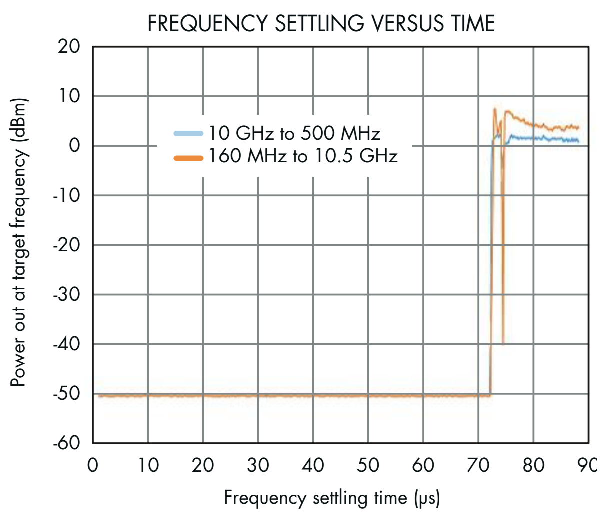
Testing of RF/microwave semiconductors, components, and systems incorporated in everything from commercial wireless systems to military radar applications often involves the ubiquitous signal generator. These instruments may be employed for continuous-wave (CW) or pulsed signal generation, local-oscillator (LO) substitution when evaluating receivers and transmitters, and stimulus and response measurements.

When selecting a signal generator for an RF/microwave test system,[1] it is important to understand the key specifications like output power, phase noise, level accuracy, spurious levels, and harmonics. However, one shouldn't take a casual approach to such details as frequency switching speed and calibration time, which may be critical to a particular application.

The limits of a signal generator will be the limits of a measurement system's capabilities, especially when characterizing high-performance devices under test (DUTs). For example, when testing an amplifier with a signal generator exhibiting high levels of harmonic distortion or spurious signal content, it becomes difficult to determine whether a test system's analyzer is measuring the amplifier's or signal generator's performance. By better understanding signal-generator specifications, one is able to more clearly discern the tradeoffs between price and




**1. These are the typical phase characteristics for a commercial signal generator, which in this case is the modular PXIe-5654 from National Instruments.**




**2. The frequency-settling-time characteristics of the NI PXIe-5654 are plotted for frequency transitions of 10.0 to 0.5 GHz (blue trace) and 160 MHz to 10.5 GHz (orange trace).**

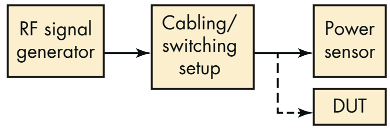
performance, and the right source can be found for a particular application.

## PHASE NOISE, OTHER VITAL SPECS

Test-and-measurement requirements vary according to the end system, but for many applications, including communications and radar systems, signal-generator phase noise *(Fig. 1)* is critical in determining the dynamic range and signal sensitivity of a test system. High phase noise reduces a radar system's efficiency in resolving closely spaced targets or tracking slow- and fast-moving targets simultaneously. Similarly, in wireless comm systems, high phase noise reduces a receiver's selectivity to switch between narrow radio channels, leading to high bit error rates (BERs).

CW signal generation in verification tests such as intermodulation-distortion (IMD) measurements, noise figure measurements, phase-noise tests, and third-order-intercept (TOI) measurements requires a signal generator with high spectral purity. High spectral purity refers not only to low phase noise, but also low harmonic levels and low spurious content.

The harmonic performance of a signal generator must be analyzed separately from other spectral-purity parameters (e.g., spurious noise or phase noise), depending on the application under test or the frequencies required for a test. In general, a signal generator will not exhibit low harmonics across its entire frequency range. However, some signal generators are designed with internal filters, such as highpass filters, to reduce harmonic signal levels across different frequency bands. This is generally true at low frequencies for a broadband signal generator.

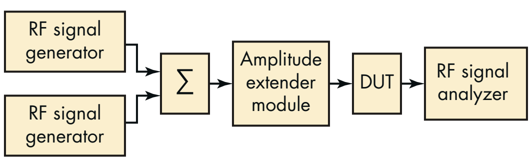



**3. A power meter connected to the output of a signal generator can help save time and minimize amplitude settling errors when switching frequencies.**

Switching speed is an important signal-generator parameter for many applications, like when testing frequency-hopping radios. Fast switching synthesizers also can be valuable for production testing, since higher-frequency switching speeds mean faster test times and higher product throughput. When a signal generator or frequency synthesizer spends less time transitioning from one frequency to another during a sweep or a sequence of test frequencies, more time is available to execute measurements.

Signal generators have historically incorporated yttrium-iron-garnet (YIG) oscillators as signal sources when low phase noise was required, and voltage-controlled oscillators as signal sources when there was a need for fast frequency tuning. Because of the two traditional architectures, the notion has arisen that fast switching speed and low phase noise are mutually exclusive signal-generator parameters. However, some applications, such as testing RF integrated circuits (RFICs), may demand both low phase noise and fast switching speed.

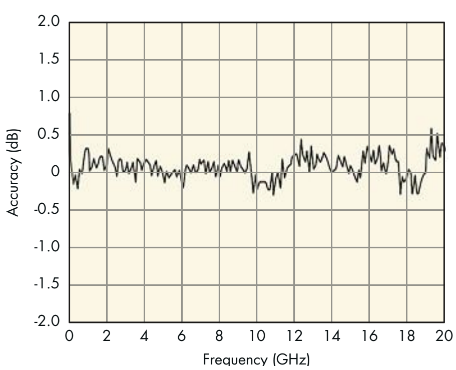
One example of an instrument that handles both parameters is the NI PXIe-5654 modular RF signal generator from National Instruments, which operates from 250 kHz to 20 GHz. It employs a low-phase-noise oven-controlled crystal oscillator (OCXO) that is optimally translated to the range of output frequencies while maintaining the OCXO's low-phase-noise profile.



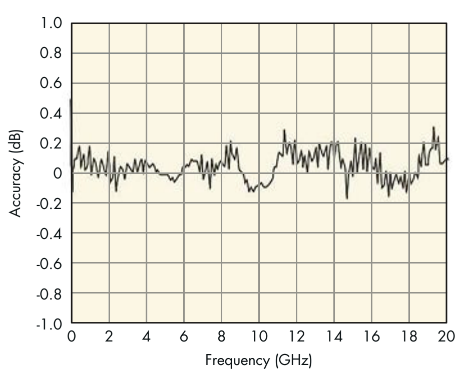

**4. ATE testing is aided by flexibility, as in this case of a single model NI 5696 amplitude extender module used with a pair of NI PXIe-5654 signal generators for two-tone testing.**

The typical phase-noise characteristics of the signal generator are shown in Fig. 1.[2] For example, at 20 GHz, the single-sideband (SSB) phase noise is –113 dBc/Hz offset 10 kHz from the carrier. It improves to –119 dBc/Hz offset 10 kHz from a 10-GHz carrier, notably better than the phase-noise performance of many microwave YIG-based synthesizers. Further from the carrier, the phase noise of the PXIe-5654 remains flat for several megahertz and then drops down to the noise floor.

Since the signal generator is based on a VCO architecture, it also provided fast frequency switching speeds.[3] At lower frequencies, phase noise improves by 6 dB/octave due to frequency division.




**5. This is the typical measured power accuracy of an NI PXIe-5654 signal generator at –100 dBm.**




**6. This is the typical measured power accuracy of an NI PXIe-5654 signal generator at –70 dBm.**

## SETTLING TIME

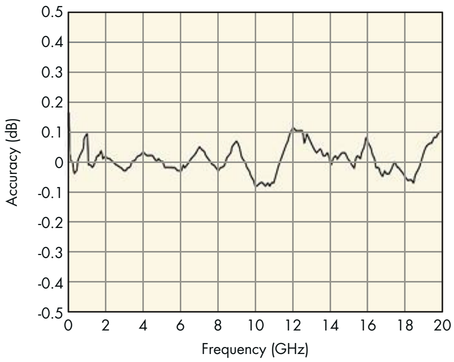
Manufacturers are under pressure to increase production-line throughput while decreasing the cost of test. At the same time, test engineers pursue more measurement data without significantly lengthening the time required for measurements. When using a signal generator, it is critical that a test engineer be familiar with all factors that impact frequency switching time and amplitude settling time.

*Figure 2* shows the frequency-settling-time characteristics of the NI PXIe-5654.[4] Two separate frequency transitions are given: The vertical axis shows output power at the target frequency, while the horizontal axis reveals the time following the trigger used to initiate a change in frequency. The blue curve indicates a frequency transition from 10.0 to 0.5 GHz, and the orange curve shows a transition from 160 MHz to 10.5 GHz.

In both cases, the frequency settles to within 5 ppm of the target frequency well within 100 µs. The instrument's VCO-based architecture makes it possible to achieve fast frequency-switching speeds throughout the frequency tuning range without depending on the size of the jump in frequency.

Amplitude settling errors will play a part in a signal generator's settling time, with fewer errors usually requiring longer switching times. If some amplitude errors can be tolerated in a measurement, faster settling times are possible. For example, with an NI PXIe-5654 signal generator, if greater than 2-dB amplitude settling error can be tolerated, a 100-point sweep can be completed in about 30 ms.

By performing such a measurement in list mode, amplitude errors can be measured and corrected for all points with the aid of a power meter *(Fig. 3)*. This technique can ultimately shave off hundreds of milliseconds to seconds from every frequency sweep.




**7. This is the typical measured power accuracy of an NI PXIe-5654 signal generator at –40 dBm.**

Understanding how software, such as list-mode functions, can be applied to a particular signal generator helps decrease test time while still minimizing amplitude settling errors. Switch points (frequency and power-based) and mechanical attenuators can add significant time to frequency sweeps with hundreds of points.

However, changing the state of an instrument's mechanical attenuator can decrease settling time by 20 ms. For example, the datasheet for the NI PXIe-5654 provides guidance on how factors such as mechanical attenuators can impact sweep times.

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### FLEXIBLE ARCHITECTURE

High-volume production testing often requires multiple racks of test signal generators. Modular instruments such as the PXI-based NI PXIe-5654 occupy a fraction of the volume of traditional 19-in.-wide rack-mount instruments while allowing for additional complementary, compact modules like the PXIe-5696 amplitude extender module. This module's amplitude level control (ALC) performs corrections in the amplitude control circuitry of the PXIe-5654, resulting in a leveling of power from –110 to +30 dBm across a frequency range of 250 kHz to 20 GHz.

To illustrate the flexibility possible with a modular architecture, two PXIe-5654 signal generators were used with a PXIe-5696 amplitude extender module for two-tone power-amplifier (PA) and front-end-module (FEM) testing *(Fig. 4)*. Normally, a single module would be insufficient to make amplitude corrections for two separate signal generators. But in this case, the flexibility allows for simplified two-tone testing, with signals from a PA or FEM fed to a signal analyzer for evaluation.

A signal generator's output power is another important specification because of the loss of signal power through cables and switches leading to a DUT in a test setup. When specifying a test signal source, sufficient margin should be allocated for output power to compensate for such losses in the test setup. It is much easier to drop signal levels with an external attenuator (which is passive) than to boost signal levels with an external amplifier (which requires bias energy).

Some tests (e.g., PA characterization) require high signal output levels from a signal generator while maintaining high level accuracy and good spectral purity. Power accuracy is critical because a DUT's response is likely to vary with the signal-generator power level. For such requirements, multiple RF attenuators may be used to extend the dynamic range of a signal generator's output power, along with an ALC circuit to increase the accuracy of the output signal.

To demonstrate how power accuracy can change at different signal-generator output-power levels, the typical power accuracy of the PXIe-5654 signal generator with a PXIe-5696 module is plotted in *Figs. 5, 6,* and *7* for output levels of –100, –70, and –40 dBm, respectively. mw




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TOMMY NEU | System Engineer
*Texas Instruments*
*e-mail: ti_thomasneu@list.ti.com*

# Cancel Noise in RF Sampling Observation Receivers

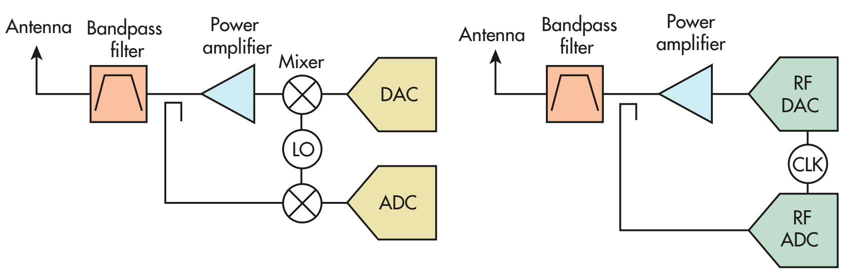
**The common LO approach used with frequency mixers can also be applied to clocks for RF sampling data converters for noise reduction in microwave receivers and transmitters.**

Observation receivers are often employed in radar systems or communications systems to check on the signal quality and activity within a transmit/receive system. When signals are transmitted and received within the same frequency spectrum, observation receivers often use a common local-oscillator (LO) architecture to improve noise performance. The approach is effective for observation receivers for a variety of applications, including communications and radar.

The use of digital predistorton (DPD) in cellular communications base stations, for example, can allow the system's transmit power amplifier (PA) to operate in its nonlinear region with higher efficiency than is possible in its linear region. The unwanted signal-distortion products are reduced or cancelled by intentionally predistorting the transmitted signal waveforms, with the resulting linearized output of the PA being measured by the observation receiver as a means of monitoring signal quality.

*Figure 1 (left)* shows the use of a common LO for each mixer in the transmit and feedback paths of an observation receiver system. The layout employs a DPD algorithm to correct for the nonlinear distortion of the PA, subtracting and eliminating the unwanted noise and distortion of the LO that mixes with the transmit signal. The common LO approach is also used in radar. However, in a radar system, the primary objective is to improve the dynamic range and target-detection capability of the receiver rather than the efficiency of the exciter.

As RF systems evolve—taking advantage of available higher-speed data converters for digitizing and generating signals at RF and microwave frequencies—the common LO approach can be implemented in the digital realm for effective reduction of noise in observation receivers using high-speed, high-resolution analog-to-digital converters




**1. Closed-loop feedback is used for noise cancellation in a transmit power amplifier system (left) with a predistortion heterodyne system and in a direct RF sampling system (right).**

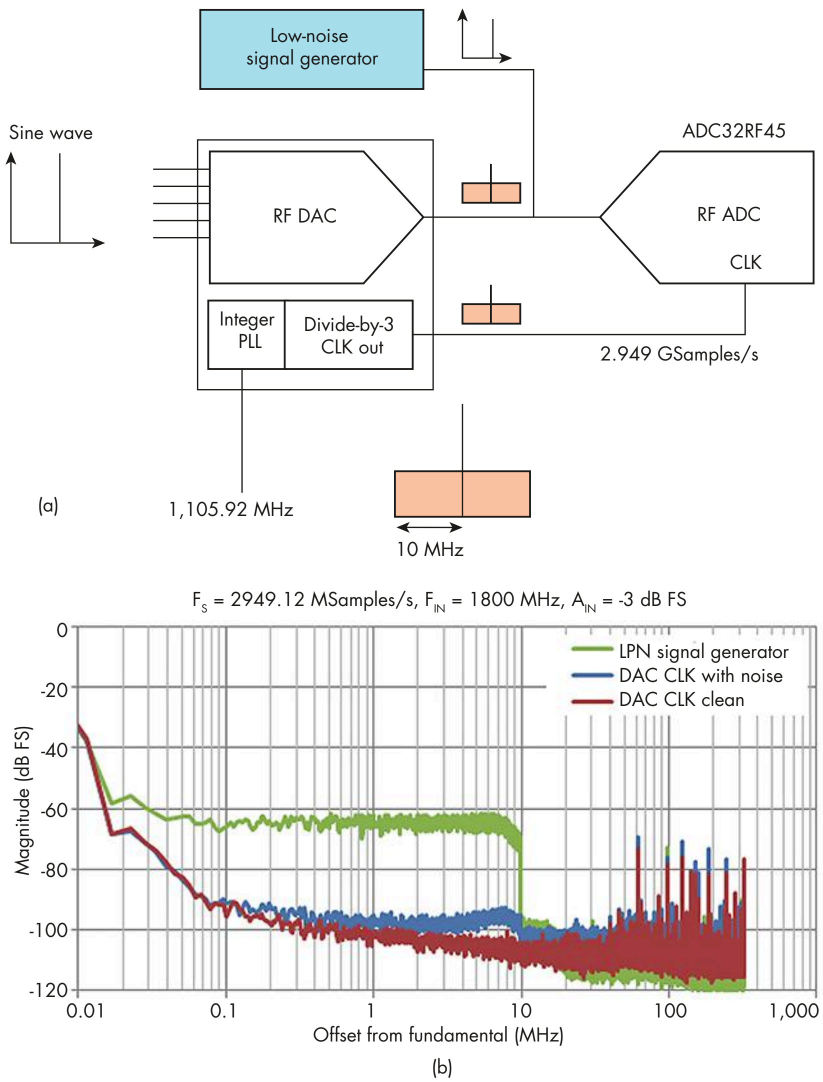
(ADCs) and digital-to-analog converters (DACs). System engineers are finding the benefits of using high-speed RF sampling ADCs such as the model ADC32RF45 from Texas Instruments (www.ti.com).

Such data converters provide a high level of integration in support of compact observation receivers. And at the same time, they offer a wide frequency range and high sampling speeds that make it possible to eliminate a frequency downconversion stage in a traditional heterodyne receiver design (along with all the associated components).

When using a direct RF sampling data converter in a receiver design, the sampling clock is the equivalent of an LO in an analog receiver with intermediate-frequency (IF) stage *(Fig. 1, right)*. Having a common clock with data converters in RF-sampling-based systems is akin to using a common LO with mixer-based frequency-conversions systems to achieve correlated noise cancellation.

To determine the magnitude of noise cancellation possible by using the common clock approach with multiple data converters in an RF-sampling-based

*(continued on p. 90)*




**2. This test setup (a) uses 10-MHz noise pedestals to inject a controlled amount of noise, resulting in the normalized FFT plots (b).**

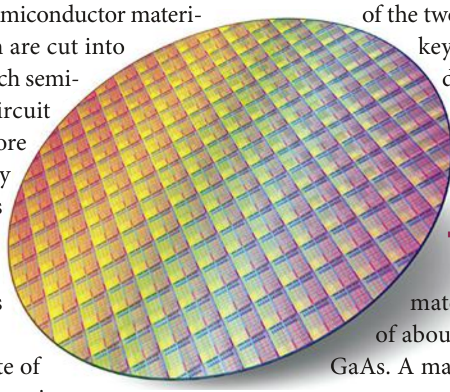
JACK BROWNE | Technical Contributor

# What's the Difference between GaN and GaAs?

**GaN has emerged as the leading semiconductor material for high-power microwave switches and amplifiers, although GaAs is still the material of choice for low noise.**

During the last decade, gallium nitride (GaN) has become the favorite high-frequency semiconductor compound, steadily replacing gallium arsenide (GaAs) in many RF/microwave applications, especially where higher-frequency, higher-power semiconductors are required. But why the steady shift to GaN, and just how different in performance are GaAs and GaN?

GaN and GaAs are both compound semiconductor materials, grown in the form of ingots, which are cut into thin wafers (*see figure at right*) upon which semiconductor devices, including passive circuit elements, are fabricated. GaAs is the more mature material and is commercially available in the form of wafers as large as 6 in. in diameter. GaN, which has been used to fabricate LEDs since the 1990s, is typically available in wafers as large as 2 in. in diameter.



**GaN and GaAs are two of the semiconductor substrate materials used for high-frequency solid-state devices, fabricated on thin wafers.** *(Image courtesy of Thinkstock)*

GaAs is well established as a substrate of choice for high-frequency, small-signal semiconductor devices, especially where low noise figure is needed, as in receiver front ends. GaAs monolithic microwave integrated circuits (MMICs) are widely used in portable wireless products, such as smartphones, tablets, and Wi-Fi devices. Components such as switches and amplifiers are typically incorporated into these GaAs MMICs, which are designed for operation at low voltages and currents typically available from a battery.

GaN, on the other hand, has come to be known as a power process, capable of fabricating active devices for amplifiers that can operate at voltages of +48 V dc and higher. With the higher-voltage capabilities of GaN devices and MMICs, they have become the active components of choice for such applications as power amplifiers in wireless base stations, and have been steadily replacing high-frequency electron vacuum tubes in military radar. For a comparable output-power rating, GaAs amplifiers tend to be more linear, with less distortion, than GaN amplifiers.

Before attempting to compare differences in devices fabricated on the two high-frequency semiconductor materials, however, it is only necessary to assess the differences in characteristics of the two III-V compound semiconductors. These key material characteristics include relative dielectric constant (relative to the dielectric constant of a vacuum), breakdown voltage, electron mobility, saturation velocity, and thermal conductivity.

## THE GAP IN BANDGAP

GaN is considered a wide-bandgap material compared to GaAs, with a bandgap of about 3.4 eV for GaN compared to 1.4 eV for GaAs. A material's bandgap related to the amount of energy required to shift an electron from the top of the valence band to the bottom of the conduction band within a semiconductor formed on that material. A wide bandgap typically refers to a material with bandgap of greater than 1 or 2 eV.

GaN typically exceeds GaAs in material parameters relating to higher energy and power, and in the speed of achieving higher-energy states. For example, the saturation velocity of GaN, at $2.7 \times 10^7$ cm/s, is somewhat higher than the $2.0 \times 10^7$ cm/s of GaAs. The critical breakdown voltage field determines the highest voltage that can be safely applied to a solid-state device, and the breakdown electric field of GaN, at $4 \times 10^6$ V/cm, is much higher than the $5 \times 10^5$ V/cm of GaAs.

GaN also has a much higher relative dielectric constant (at 9.0) than that of GaAs (at 1.28), allowing for the fabrication of much higher-valued capacitors in support of higher-power devices and MMICs on GaN than on GaAs. In terms of achieving higher-frequency device operation, however, GaAs excels, with a much higher electron mobility than GaN, at about 6,000 cm2/V-s compared to the approximate electron mobility of 1350 cm2/V-s for GaN.

GaN has certain traits that support smaller circuits for a given frequency and power level, allowing the higher power densities and efficiencies much sought after by designers of power-efficient wireless base stations and microcells. For one thing, the higher-voltage capacities of GaN allow the fabrication of much smaller devices for a given power level than on GaAs materials. For example, the defect density of any semiconductor wafer will limit the practical size of circuits that can be manufactured repeatably and reliably on that wafer, implying that device area be minimized for best production yields.

Because the power density of GaN materials is much higher than GaAs or even silicon semiconductor materials, thermal conductivity is an important material parameter for characterizing how well a device will dissipate heat due to dielectric and conductor losses, as well as basic device inefficiencies. The thermal conductivity of GaN, at 1.7 W/cm-K, is more than three times the thermal conductivity of GaAs, at 0.46 W/cm-K. High thermal conductivity translates into the lowest temperature rise at conduction, a characteristic that enables GaN devices to handle higher power levels than GaAs devices using the same device structure, such as a field-effect transistor (FET).

### MATERIAL DIFFERENCES?

GaN devices are currently fabricated on different substrate materials, such as GaN on silicon (Si) and GaN on silicon carbide (SiC) wafers, with some debate about which process offers the best performance. Some larger companies, such as Raytheon Co. (www.raytheon.com), maintain both GaAs and GaN foundries as part of their in-house capabilities in support of military applications. Many commercial foundries will offer details on the benefits of each process with some foundries, including WIN Semiconductors Corp. (www.winfoundry.com), Global Communication Semiconductors LLC (www.gsinc.com), and Qorvo (www.qorvo.com), offering different forms of GaN processes along with GaAs fabrication services as well. For those wishing a finer-grained comparison of GaN and GaAs materials, MACOM (www.macom.com), with products based on more than a half-dozen semiconductor processes, offers a detailed comparison of the different semiconductor materials on its website. mw



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# Raytheon to Aid Aegis Missile-Guidance System

Raytheon Co. has been awarded a $365 million fixed-price-incentive, cost-plus-fixed-fee contract from the U.S. Navy for production of critical components for the Aegis missile-guidance system.

The contract covers the AN/SPY-1D(V) radar transmitter, MK 99 missile-fire-control system, and related engineering services for those subsystems within the Aegis system. The contract combines purchases for the U.S. Navy and the governments of the Republic of Korea and Japan under the Foreign Military Sales program. With options, if exercised, the overall contract could extend to $423 million.

Aegis uses S-band phased-array radar to acquire and track multiple targets. The single-ship system integrates within a network of ships and Aegis systems on those ships. ■

*(News continued on p. 60)*


Aegis is a missile-guidance system deployed aboard U.S. Navy vessels and ships for allied troops.

# A Soldier's Place on an Unmanned Battlefield

**TACTICAL UNMANNED** aerial vehicles (UAVs) have already become a reliable component of many surveillance and signal intelligence (SIGINT) operations for the U.S. Army, as well as part of civilian border patrols between countries. Major contractors such as Lockheed-Martin are well entrenched into UAV technology, with the firm's Desert Hawk recently making its 100th flight.

The U.S. Army is not the only customer for robotic systems, however. Another major contractor, Northrop-Grumman, has been at work for the U.S. Navy for the past decade as part of the Navy's Unmanned Combat Air System (UCAS). One of the successes of that program is the X-47B, a fighter-sized UAV capable of unmanned surveillance, strike, and reconnaissance activities. This is, in fact, an autonomous vehicle that can land and take off on its own and recently even demonstrated autonomous refueling while in the air. The Navy's goal is to establish a permanent unmanned battle-ready fleet of such unmanned vehicles.

As multiple sensors and radar technology continue to be designed into commercial land vehicles, and the specter of the driverless automobile looms on the horizon, the transportation departments of different states in this country are planning for such things as "autonomous lanes" on major highways, such as California's famed route 101. As IBM continues to push the limits of cognitive computing by recently programming emotions into its supercomputer Watson, the development of "intelligent" drones and robots for the battlefield will soon follow. If battlefield robots are armed with their own decision-making capabilities, the question will inevitably arise as to how much the humans "controlling" those robots should be involved, and what will be the impact of human involvement on the battlefield.

In the future, a soldier's place on the battlefield may be far from the action, remotely piloting drones or directing robotic infantry from the screen of a mobile computer or the equivalent of a tactical-grade smartphone. Whether video games are mimicking life or vice versa, the humans may well be far removed from the battlefield, with remotely controlled drones and robots from one side attempting to break through an adversary's defenses to get at the humans.

# VadaTech Targets DRFM with RFSS Acquisition

**VADATECH HAS** acquired Radio Frequency Simulation Systems Inc. (RFSS), which includes that company's expertise in digital RF memory (DRFM) technology. VadaTech, a supplier of embedded circuit boards, supporting software, and integrated subsystems notably for radar systems, will continue to support and improve on the DRFM technology, which is vital to many military electronics systems, including electronic-countermeasures (ECM), identify-friend-or foe (IFF), and radar systems.

Saeed Karamooz, chief executive officer (CEO) of VadaTech, says, "The natural synergies between the product sets of RFSS and VadaTech will provide great results for customers in terms of time-to-market and functionality for their next-generation platforms. This acquisition is in line with VadaTech's philosophy of providing customers with access to cutting-edge technology, and we look forward to creating innovative solutions together."

Richard Damon, president and CEO at RFSS, adds, "RFSS customers will benefit from improved performance and reliability, and dramatic reductions in the size, weight, power, and cost (SWAP-C) of their solutions thanks to integration with VadaTech's advanced hardware modules. VadaTech's global sales and distribution network also means more local support and capability."

**Richard Damon, President and CEO of RFSS (right), is welcomed by Saeed Karamooz, CEO of VadaTech.**

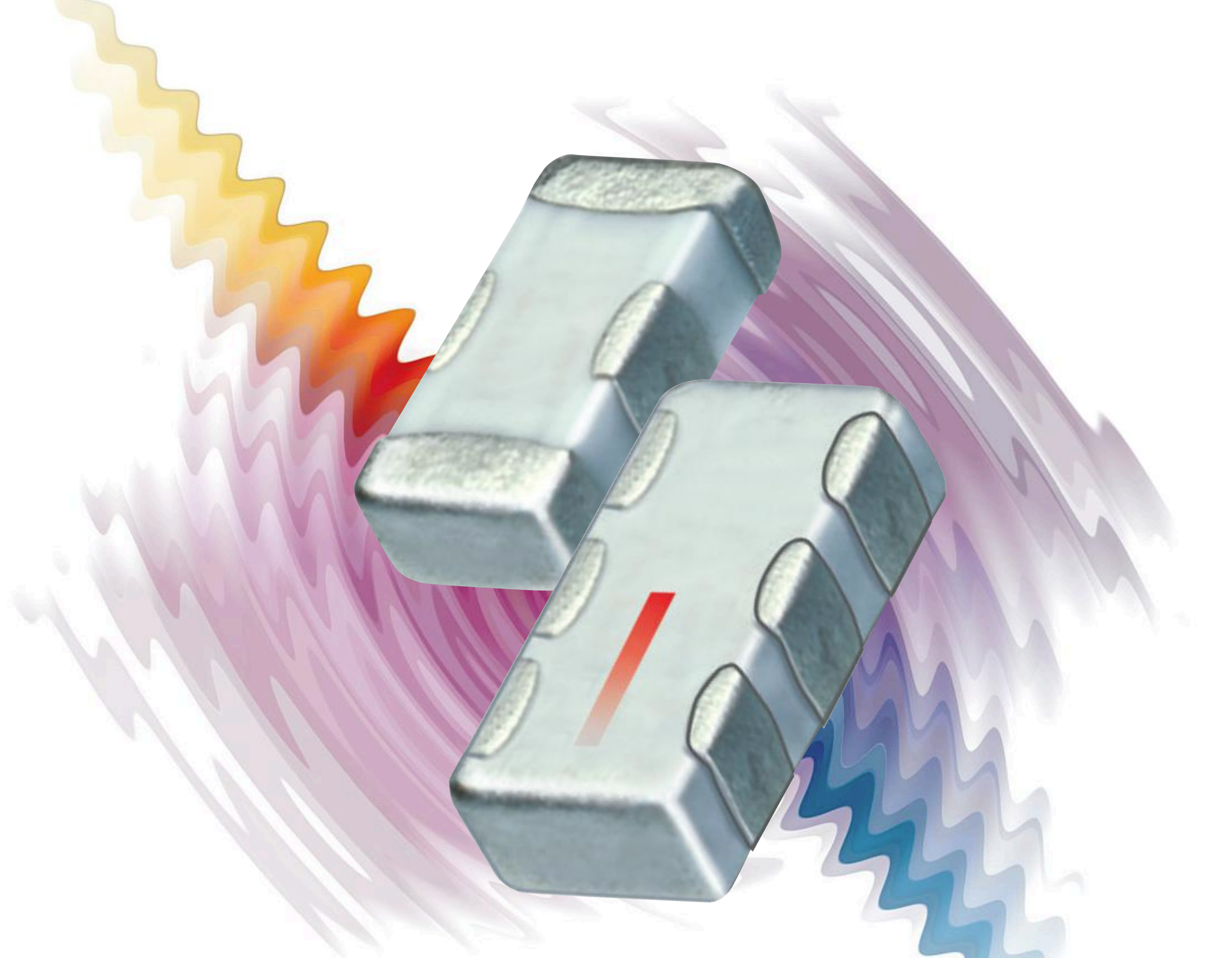
DRFM relies on advanced data converters, such as analog-to-digital converters (ADCs) and digital-to-analog converters (DACs), capable of maintaining high signal integrity. It is used for simulators as well as in-field systems, including radar target generators, radar environment simulators, IFF simulators, and ECM target generators. Such systems are invaluable for testing and training applications. ■

# GSA Contract Streamlines Acquisition of X-COM Products

**X-COM SYSTEMS** LLC, a subsidiary of Bird Technologies, announced that it was awarded a contract by the Government Services Agency (GSA) for the purchase of its products online by federal agencies. The contract allows customers to use the GSA Advantage! online shopping and ordering service to procure goods and services from X-COM Systems (www.xcomsystems.com). The firm designs and manufactures wideband RF/microwave signal recording and playback systems; software tools for visualization, analysis, and editing; and RF/microwave signal-generation tools for defense and commercial applications.

The GSA Advantage! service is a purchasing portal that simplifies the procurement procedure for federal agencies while also providing discounted pricing. It is meant to eliminate the delays and overhead associated with traditional screening and procurement procedures by eliminating cost and price analysis of comparable products.

By accepting products for the portal, the GSA has already established that pricing is "fair and reasonable" and listed products are deemed acceptable for government-related use. Prospective customers can view X-COM products and pricing on GSA Advantage! by visiting www.gsaadvantage.gov. ■





# Radar Technology Tightens Border Patrol

**RADAR TECHNOLOGY** provides many tactical advantages during warfare, but it can also serve well in civilian applications, including for border security and surveillance. The patented SharpEye radar technology from Kelvin Hughes (www.kelvinhughes.com) has been used to detect and track ground-based and aerial targets in difficult-to-access locations such as border crossings between countries.

The solid-state radar system employs pulse-compressed Doppler radar techniques at X-band frequencies. It requires no maintenance or service and is less affected by environmental and weather factors, such as rain and snow, than higher-frequency surveillance radar systems.

One version of the system, the SharpEye SxV, is a mobile, lightweight self-contained unit that weighs around 20 kg and can be readily transported to different locations for deployment on a mast or tripod. The radar is able to be deployed along a border as part of a multi-node system or deployed as a mobile-vehicle-mounted surveillance package.

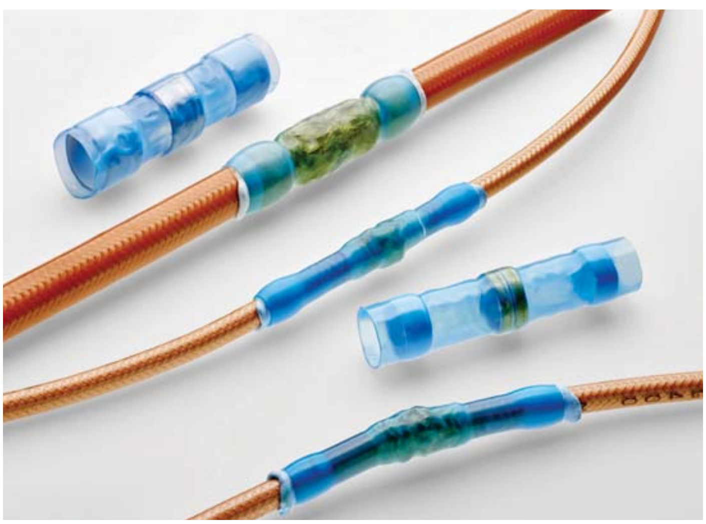
A more permanent version of the system, the SharpEye Long Range system, features co-located radar and electro-optical subsystems. With simple setup, it delivers 360-deg. radar and camera surveillance. The system uses gallium-nitride (GaN) amplification, with its transceiver contained in the antenna turning mechanism. It employs a 5.5-m, open-array, low-profile antenna configuration.

Jonathan Field, Director of Security Systems for Kelvin Hughes, explains, "The increase in demand that we are seeing for our border-control and surveillance radar applications is a reflection of the many benefits our SharpEye radar technology can deliver—high performance, high reliability, easy deployment, versatility, and significantly reduced through-life costs." ■

# MATCHED-IMPEDANCE SPLICES Save Aerospace Cables

**TE CONNECTIVITY** Ltd. (www.TE.com) developed Raychem matched-impedance splices that solve the problem of removing and replacing damaged coaxial cables for aerospace applications while in use. The splices, which comply with MIL-PRF-32517, help to maintain the characteristic impedance of the repaired cables and systems.

According to Janeann Avants, product manager, Global Aerospace, Defense & Marine, TE Connectivity, "Raychem matched-impedance splices reduce the time and effort needed for repairs and lessen the number of cables that need to be replaced."



The matched-impedance splices are designed for both military and commercial aerospace applications. They can handle wide temperature extremes, high shock and vibration, and corrosive environments. A splice contains three components: a hexagonal crimp barrel for the center conductors, a dielectric shell that helps maintain cable geometry for impedance control, and a heat-shrinkable Solder-Shield splice that both terminates the cable's shield and provides sealing to protect the splice environmentally. ■

JACK BROWNE | Technical Contributor

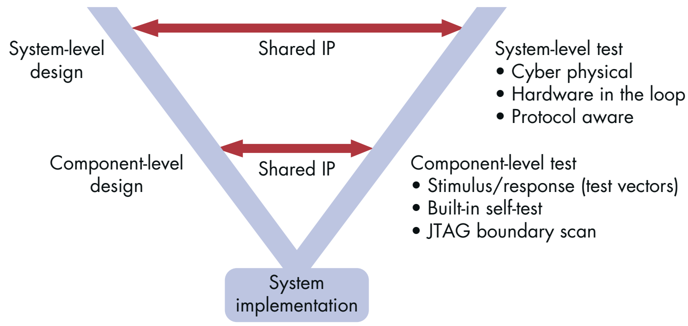
# Predicting the Performance of Defense Electronic Systems

**High-level software programs can simulate the performance of tactical communications and radar systems, as well as how they behave under changing environmental conditions.**

HIGH-LEVEL SOFTWARE programs can simulate the performance of tactical communications and radar systems, as well as how they behave under changing environmental conditions.

Computer simulations have enhanced the efforts of RF/microwave circuit designers for many years, providing precise models for many of the active and passive components comprising high-frequency circuits. Simulation software can even account for the effects of dielectric and conductor losses in circuit materials.

System designers have also come to rely on software to predict the performance of a wide range of designs, including communications systems, electronic-warfare (EW) systems, and radars. By using a variety of software simulation tools, they can quickly evaluate changes in a system block diagram.



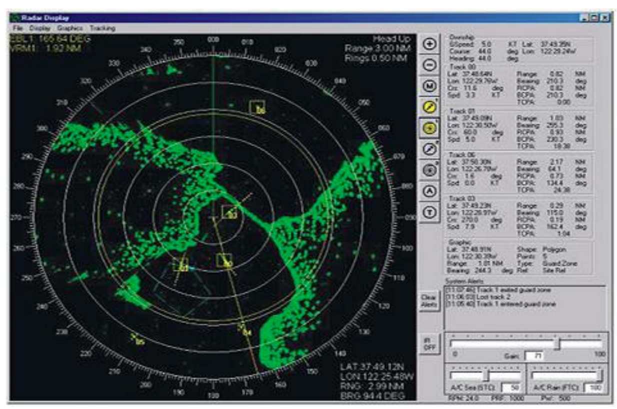

**1. Many system simulators rely on tight integration with component-level simulation software and links to test equipment for effective modeling.** *(Graphic courtesy of National Instruments)*

System simulators for defense electronic systems have traditionally performed simulations based on a block diagram, such as from an antenna through receiver and transmitter to a baseband processor. Often, separate simulations may be performed on different types of antennas, with modeling then performed on the different function blocks of a system (e.g., receivers, transmitters, or baseband processors).

Some major contractors with extensive experience in radar systems, such as Rockwell Collins (www.rockwellcollins.com), have developed their own software simulation tools for many different forms of radar—such as fire-control, weather, navigation, and search-and-surveillance systems—with customizable capabilities for each system type. These high-level simulation programs can take into account the effects of weather, the terrain, and electrical variations.

Whether for radar, EW, or communications simulations, most effective system simulators start with a building-block approach based on models of components or function blocks within a system, such as amplifiers, filters, and mixers *(Fig. 1)*. Numerous commercial system simulators are built upon this approach, including the Advanced Design System (ADS) and SystemVue software from Keysight Technologies (www.keysight.com). Another prominent offering is the Visual System Simulator (VSS) from Applied Wave Research (www.awrcorp.com) and its parent company, National Instruments (www.ni.com).

SystemVue, for example, which includes radar system examples, is tightly linked to the company's ADS software. The latter typically works at component levels in the design of RF/microwave circuits and draws upon modeling the interactions of different components at the system level, whether in commercial or military system designs. While the impedance matches into and out of a small-signal transistor may affect the gain and noise figure of a front-end amplifier based on that transistor, ADS can extend impedance-matching effects from the component to the



**2. The PCRadar simulation software was designed for the U.S. Navy and Coast Guard for training applications.** *(Graphic courtesy of Buffalo Computer Graphics)*

system level to study the effects between the amplifier and other connected components on the sensitivity and selectivity of a communications or radar receiver.

In fact, Keysight Technologies, in its former incarnation as Agilent Technologies (www.agilent.com), offers an excellent white paper on the application of its ADS software to simulating radar and EW systems. “Advanced Design System Connected Solutions for Radar and EW Systems” is available as a free download from the still-active Agilent website.

The VSS software is seamlessly integrated with AWR’s Microwave Office software, which is typically used at the component and circuit levels, enabling the combination of software tools to perform simulations flowing from the device through system levels.

To meet the needs of radar designers, the VSS for Radar Systems is a specialized version of the software developed for modeling different radar systems, including ground-, air-, space-, and ship-based radars. Radars can be simulated according to different frequencies and waveform types, as well as by types of antenna.

VSS software includes links to commercial test equipment like signal generators and vector network analyzers (VNAs), helping to integrate measured data into modeled simulations. In addition, the VSS Radar Library includes models of the various components found in different radar systems.

Due to the widespread use of radar technology in civilian and military applications, the field for radar system simulators has grown at a steady pace. Some of these simulation tools are written for standard Windows-based PCs, such as PCRadar from Buffalo Computer Graphics (www.buffalocomputergraphics.com). The software provides an automatic radar plotting aid (ARPA) display on a PC monitor and serves as an excellent educational tool for shipboard radar systems *(Fig. 2)*.

COMSOL’s MultiPhysics (www.comsol.com) is another versatile simulation software package that has been used for predicting very specific effects within phase-array and other types of radar systems. The software has been used, for example, to model different frequency-selective surfaces (FSSs) and their radar cross-sections (RCSs). By finding an FSS with minimal RCS, a jet aircraft or missile can be designed to make it more difficult to detect by enemy radar.

COMSOL MultiPhysics has also been used to predict system-level effects previously not modeled in defense systems, such as corrosion in metals. The software tool, when equipped with its Corrosion Module, has been used by the Naval Research Laboratory (NRL) to predict how pits grow in different metals as a function of corrosion.

System simulators are, after all, collections of equations, typically organized with a graphical user interface (GUI) that simplifies the application of those equations when analyzing system behavior. For those who want a closer hand with the equations, MATLAB from MathWorks (www.mathworks.com) has proven to be an effective tool for modeling radar-system behavior. In particular, when used with the company's Simulink block-diagram-based system simulation software, MATLAB supports modeling and simulation at all stages of a radar system's development cycle.

Electromagnetic (EM) simulation software like the various EM-based tools from Remcom (www.remcom.com) have been widely used for modeling antennas and other radar-system components in addition to performing full system simulations. The software has helped analyze RCS patterns, antenna radiation, bistatic scattering, and other characteristics of military and commercial radar systems.

For those seeking a painless entry to radar simulation, Apponic (www.apponic.com) offers a no-charge simulation (based on its use of MATLAB software) of an early-warning radar system, while Software Informer (www.radar.software.informer.com) provides free Windows-based radar simulation software on its website. de

DOMINIC J. TESTO | Product Manager

*Specialty Silicone Products, Inc., 3 McCrea Hill Rd., Ballston Spa, NY 12020; 518-885-8826, www.sspinc.com*

# Particle-Filled Silicones Satisfy EMI Shielding Needs

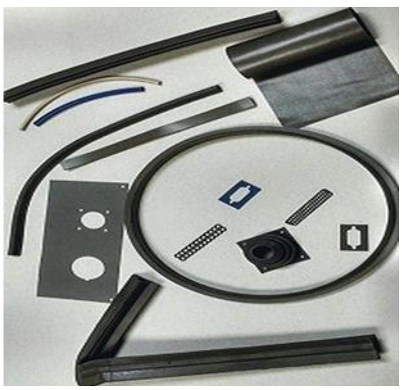
**Silicone materials filled with conductive particles provide high levels of shielding and ease of use, compared to traditional shielding solutions, in a wide range of applications.**

ELECTROMAGNETIC INTERFERENCE (EMI) can disrupt military electronics systems and endanger the lives of war-fighters who depend on those systems. The causes of EMI are many, occurring wherever electromagnetic (EM) fields are produced. Sources include electric motors, radio transmitters, computer circuits, and power lines.

In some cases, such as military jammers, EMI is intentionally generated to disrupt tactical radios and other military electronic systems. EMI can also cause problems for civilian electronic systems—e.g., different types of vehicular electronic systems—as well as upset commercial communications and medical electronic devices. Fortunately, properly applied EMI shielding can solve the problem.

Historically, EMI shielding has been fabricated from metal sheets and formed into shapes as required to fit an electronic housing (a radio enclosure, for instance) as a barrier against EMI. Sheets made from aluminum, copper, and steel provide rigidity and strength, but can deform under the mechanical pressure required for sealing. Once deformed, metal EMI shields tend to remain in that shape and may not effectively block EMI, allowing leakage to and from electronic circuitry. Furthermore, some metals are susceptible to rust, corrosion, and oxidation, and can lose integrity over time.

Modern EMI/RFI shielding materials include flexible metal screens, metal wires, and metal foams. Coatings made of metallic inks are applied to the interiors of electronic enclosures to add EMI shielding. Each EMI shielding method offers certain advantages, but different electronic devices have different requirements. Silicone shielding elastomers filled with metal particles or metal-coated particles represent a versatile shielding solution, since these compounds combine the material properties of silicone rubber with the electrical properties of metals.



**1. This silicone is filled with silver-plated-aluminum particles for high SE over wide temperature ranges. It meets the requirements of MIL-DTL-83528, Type B.**

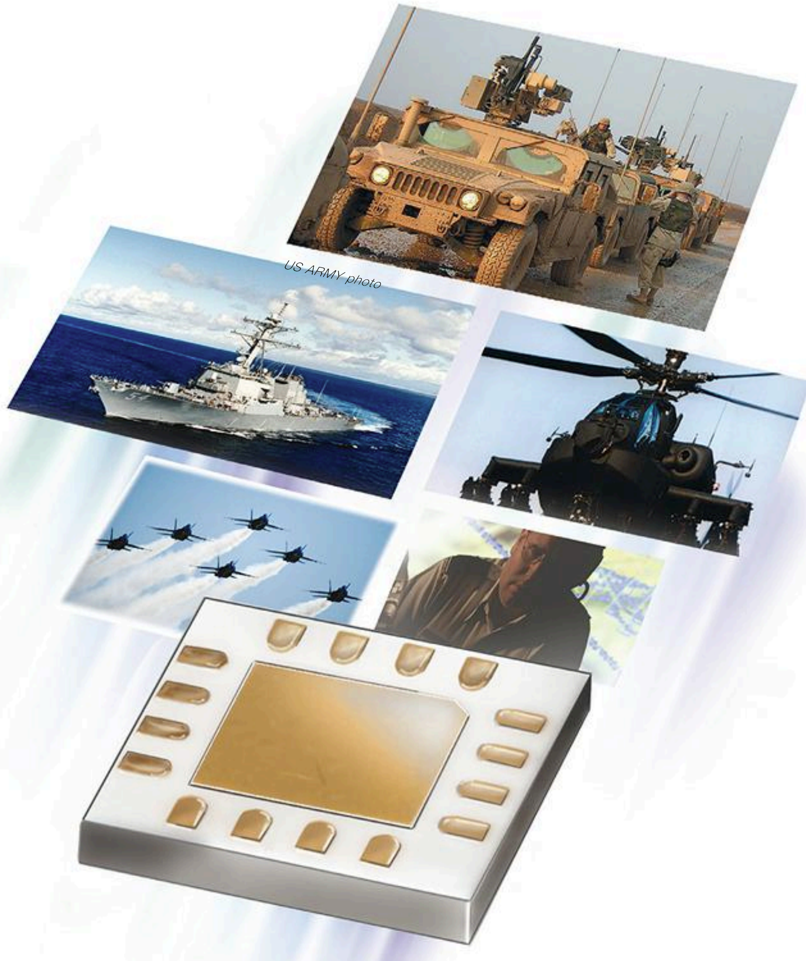
## SEALING AND SHIELDING

Silicones are a family of synthetic rubbers that provide thermal stability over a wide temperature range (typically −55 to +300°C) and resist the passage of water, ozone, and ultraviolet (UV) light. Silicone rubber is also capable of forming tight environmental seals, remains flexible at low temperatures, and stiffens at high temperatures. In addition, silicone retains elastic properties even after long periods of compressive stress. Conductive silicones are available as sheet stock, as extrusions, and as ready-to-mold compounds.

When filled with conductive particles such as silver-plated aluminum or nickel-coated graphite, silicone compounds combine excellent environmental sealing capabilities with consistent electrical conductivity and proven EMI shielding. MIL-DTL-83528, a Defense Logistics Agency (DLA) specification for electrically conductive elastomer shielding gaskets, establishes minimum shielding effectiveness (SE) levels from 20 MHz to 10 GHz for 12 material types. MIL-DTL-83528 also specifies the hardness or durometer (Shore A) of the different material types, with some designated as low, medium, or high durometer.

Due to recent advances in silicone compounding, newer particle-filled silicones can meet MIL-DTL-83528 SE requirements; such SE performance also serves as a useful benchmark for other demanding applications in commercial and industrial areas. Historically, particle-filled silicones came with significant drawbacks and were not a first choice for solving EMI shielding issues in military electronic designs. Older silicone EMI shielding compounds have been harder, higher-durometer rubbers with poor compressibility. They were also limited to higher-costing conductive fill materials, such as silver-plated copper and silver-plated aluminum.

Newer particle-filled silicones provide much improved EMI shielding performance. Still, doubt remains as to whether


US ARMY photo

these newer, softer silicones can meet the needs of the most demanding EMI shielding requirements, especially for SE performance. To better understand the capabilities of such flexible materials for rigorous aerospace and defense-based EMI shielding requirements, it may help to evaluate several particle-filled silicones from Specialty Silicone Products (SSP; www.sspinc.com), and how they were used in an actual application.

## SOFTER SILICONES, HIGHER SE

Newer particle-filled silicones for EMI shielding include lower-durometer compounds that resist tearing—a problem that can occur during gasket fabrication due to "pulling" during cutting. For example, softer silicones are available from SSP with durometer values of 30 and 40 and tensile strengths of 90 and 120 psi, respectively. For applications requiring increased tear resistance, harder particle-filled silicones with greater tensile strength are also available.

In addition, for greater resistance to tearing, lower-durometer, particle-filled silicones can be reinforced by means of an inner layer of conductive fabric or mesh. In comparison to older particle-filled silicone compounds lacking tear resistance, newer silicone compounds enable rugged shielding products that are thinner, smaller, and lighter than those earlier compounds, while providing improved EMI shielding capabilities.

Material mechanical properties such as durometer, tensile strength, and tear resistance are important for an EMI shield, but only some of the factors to consider when selecting a material for an EMI shield. Conductive silicones containing silver or silver-coated particles can meet the minimum SE requirements detailed in MIL-DTL-83528. As an example, one such material from SSP, a 65-durometer, silver-plated aluminum silicone, has been independently tested and certified to MIL-DTL-83528, Type B. MIL-DTL-83528, Type B materials are silver-plated, aluminum-filled silicones with an operating temperature range of −55 to +160°C that are capable of 100-dB plane-wave SE at 10 GHz.

TABLE 1: A SUMMARY OF INDEPENDENT TESTING ON SSP-2368-65 SILVER-PLATED-ALUMINUM SILICONE

| Test frequency (MHz) | Shielding effectiveness (SE) of test sample (dB) |
|---|---|
| 20 | 113.5 |
| 30 | 128.8 |
| 40 | 134.1 |
| 60 | 132.3 |
| 80 | 130.5 |
| 100 | 131.3 |
| 200 | 139.1 |
| 400 | 135.1 |
| 600 | 134.7 |
| 800 | 138.3 |
| 1,000 | 117.7 |
| 2,000 | 123.8 |
| 4,100 | 121.3 |
| 6,000 | 122.5 |
| 8,000 | 123.3 |
| 10,000 | 118.3 |

TABLE 2: A SUMMARY OF INDEPENDENT TESTING ON SSP-502-40 NICKEL-COATED-GRAPHITE SILICONE

| Test frequency (MHz) | Shielding effectiveness (SE) of test sample (dB) |
|---|---|
| 20 | 120.1 |
| 30 | 124.5 |
| 40 | 124.3 |
| 60 | 125.1 |
| 80 | 125.5 |
| 100 | 125.2 |
| 200 | 127.2 |
| 400 | 126.3 |
| 601 | 126.1 |
| 800 | 127.1 |
| 1,000 | 115.7 |
| 2,000 | 115.5 |
| 4,100 | 113.7 |
| 6,000 | 113.1 |
| 8,000 | 114.1 |
| 10,000 | 115.7 |

*Table 1* offers a summary of the results from an independent testing laboratory for this silicone filled with silver-plated aluminum at different frequencies. As a comparison, *Table 2* provides independent test results for a silicone filled with nickel-coated graphite particles.

While material properties and SE are important in selecting an EMI shielding material, so is manufacturability. For example, some EMI gaskets require an electrically conductive adhesive backing to keep the seal in place during gasket installation and product refurbishment. Conductive sheet stock provides excellent SE and is available in the right form factor for many applications, but may result in material waste with bezel-style gaskets.

In some cases, the availability of EMI shielding silicones as ready-to-mold compounds can help solve design challenges. As one example, a requirement for an EMI gasket for a military touchscreen display was handled by Stockwell Elastomerics (www.stockwell.com) using particle-filled silicones to meet all of the application requirements. These include material performance, SE, manufacturability, and—perhaps most importantly—cost. While this example involves a military application, it applies to other market areas just as well, including those with commercial and industrial applications.

In this particular application, an EMI gasket material with outstanding mechanical capabilities was needed. The military touchscreen would be deployed globally, often in rugged environments. A candidate material would need to maintain a mechanical seal under environmental extremes of desert heat and arctic freeze, keeping out dust, rain, and water during a wash down.

The customer also wanted the EMI gasket to provide some cushioning for protection from mechanical shock. In addition, the touchscreen gasket needed to be soft enough to avoid distorting

**2. These nickel-graphite-filled silicones meet demanding EMI shielding requirements with ease of manufacturability.**

or interfering with the display's touch functionality. Any candidate EMI gasket required an electrically conductive adhesive and had to meet a specific price point.

To win this defense contract, Stockwell selected a cost-effective material for both environmental sealing and EMI attenuation. The material is a silicone filled with nickel-graphite particles supplied by SSP *(Fig. 2)*. Use of the elastomer also supported the project's two distinct timelines. The first involved completing an engineering build where EMI gaskets were needed quickly to prototype testing. The second challenge was to provide EMI gaskets for production parts delivered in high quantities.

To meet the tight engineering-build deadline, Stockwell Elastomerics waterjet-cut sheets laminated with an electrically conductive adhesive from 3M (www.3m.com). The waterjet cutting process made it possible to deliver custom-cut parts within two days and without tooling costs. Once functional and EMI testing were completed, production tooling was assembled for the larger quantities.

The same nickel-graphite-filled silicone compound used to make the sheets was now used to mold rough blanks for the touchscreen display gasket. These molded blanks greatly reduced material waste while still allowing for proper adhesive lamination of the narrow wall gasket. The adhesive-backed blanks were then cut to final gasket geometry and tolerances.

This two-step approach allowed Stockwell's customer to meet its timeline and test parts without any tooling investment. In turn, this provided the client with a pricing advantage that helped win the Department of Defense bid by delivering a water-sealed touchscreen display that met EMI attenuation requirements. This military touchscreen-display project also demonstrated the value of nickel-graphite-filled silicones for demanding EMI shielding applications. de

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### STANDARD DETECTORS

| Omniyig Model No. | Frequency Range (GHz) | k Factor | TSS (dBm) |
|---|---|---|---|
| Zero-Bias Schottky | | | |
| ODZ0004A | 0.1 - 18.0 | 1200 | -52 |
| ODZ0328A | 2.0 - 18.0 | 1200 | -52 |
| ODZ0441A | 6.0 - 26.0 | 1000 | -51 |

### STANDARD COMB GENERATORS

| Omniyig Model No. | Input Frequency (MHz) | Output Frequency (GHz) | Output Power (dBm) |
|---|---|---|---|
| OHG10118 | 100 | 0.1 - 18.0 | -40 |
| OHG20218 | 20 | 0.2 - 18.0 | -35 |
| OHG51026 | 500 | 0.5 - 18.0 | -28 |
| OHG81026 | 1000 | 1.0 - 18.0 | -18 |

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### STANDARD LIMITERS

| Omniyig Model No. | Frequency Range (GHz) | Insertion Loss (dB) | Leakage Power (dBm) |
|---|---|---|---|
| Pin | | | |
| OLP2645A | 8.0 - 18.0 | 2.0 | +19 |
| OLP2726A | 2.0 - 18.0 | 1.2 | +19 |
| PL473 | 0.5 - 12.0 | 1.8 | +19 |
| OLP2652 | 2.0 - 18.0 | 2.5 | +20 |
| Schottky Turn-on | | | |
| SL048 | 2.0 - 26.0 | 2.5 | +14 |
| OLD2635A | 4.0 - 18.0 | 2.5 | +14 |
| OLD2733A | 0.4 - 18.0 | 2.5 | +14 |

Leakage Power Measured at P(in) = +30 dBm

### YIG MULTIPLIERS

| Omniyig Model No. | Input Frequency (GHz) | Output Frequency (GHz) | Output Power (dBm) |
|---|---|---|---|
| YM1001 | 1.0 - 2.0 | 2.0 - 13.0 | 6 |
| YM1002 | 0.1 | 1.0 - 12.0 | -33 |
| YM1003 | 0.2 | 1.0 - 12.0 | -28 |
| YM1004 | 0.5 | 1.0 - 12.0 | -10 |
| YM1026 | 1.0 - 2.0 | 2.0 - 18.0 | -4 |
| YM1027 | 0.1 | 1.0 - 18.0 | -40 |
| YM1028 | 0.2 | 1.0 - 18.0 | -33 |
| YM1029 | 0.5 | 1.0 - 18.0 | -22 |
| YM1087 | 0.1 - 0.2 | 1.0 - 12.0 | -25 |

RF input power on all models 0.5 to 1.0 watts.
Fast switching, MIL-Spec Hi-Reliability and units integrated with drivers, oscillators or amplifiers also available.

## YIG BAND REJECT FILTERS

| Omniyig Model No. | Frequency Range (GHz) | Ins. Loss (dB) | Bandwidth at 40 dB (MHz) |
|---|---|---|---|
| M107RX | 8.0 - 18.0 | 1.5 | 20 |
| M104RX | 4.0 - 18.0 | 2.0 | 8 |
| M105RX | 2.0 - 8.0 | 1.5 | 10 |

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| Omniyig Model No. | Frequency Range (GHz) | Ins. Loss (dB) | Bandwidth at 3 dB (MHz) |
|---|---|---|---|
| 4-STAGE | | | |
| M3064 | 6.0 - 18.0 | 6.5 | 500 min |
| M2997 | 6.0 - 18.0 | 6.0 | 400 min |
| M3513 | 8.0 - 18.0 | 6.5 | 500 min |

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|---|---|---|---|
| YOM1517 | 0.5 - 2.0 | 20-60 | 16 |
| YOM1518 | 1.0 - 4.0 | 20-60 | 16 |
| YOM1514 | 4.0 - 12.0 | 10 | 15 |
| YOM3719-5 | 2.0 - 15.0 | 20 | 13 |
| YOM1679 | 2.0 - 12.4 | 20 | 13 |
| YOM83 | 2.0 - 6.0 | 20 | 12 |
| YOM137 | 2.0 - 8.0 | 20 | 12 |
| YOM3719-4 | 8.0 - 18.0 | 20 | 14 |
| YOM3719-2 | 6.0 - 18.0 | 20 | 14 |
| YOM3719-1 | 4.0 - 18.0 | 20 | 13 |
| YOM3719 | 3.0 - 18.0 | 10 | 12 |
| YOM3676 | 2.0 - 18.0 | 20 | 15 |

We offer other models with Second Harmonic -60 dBc and Oscillators integrated with 2-stage YIG Filters.


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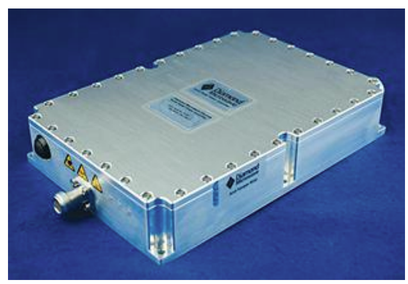

frequency range. Measuring just 220 × 150 × 41 mm and weighing about 1,900 g (excluding heat sinks), the amplifiers feature integrated monitoring and circuit protection. Self-protection includes detecting when VSWR mismatch, duty cycle, or current limits have been exceeded. Monitoring is via Ethernet connectivity to a host system. The amplifiers are equipped with a D sub control/power connector and SMA or Type N RF connectors.

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| New | CMA-84+ | DC-7 | 24 | 21 | 38 | 5.5 | 5 | 6.45 |
| | CMA-62+ | 0.01-6 | 15 | 19 | 33 | 5 | 5 | 4.95 |
| | CMA-63+ | 0.01-6 | 20 | 18 | 32 | 4 | 5 | 4.95 |
| | CMA-545+ | 0.05-6 | 15 | 20 | 37 | 1 | 3 | 4.95 |
| | CMA-5043+ | 0.05-4 | 18 | 20 | 33 | 0.8 | 5 | 4.95 |
| | CMA-545G1+ | 0.4-2.2 | 32 | 23 | 36 | 0.9 | 5 | 5.45 |
| | CMA-162LN+ | 0.7-1.6 | 23 | 19 | 30 | 0.5 | 4 | 4.95 |
| | CMA-252LN+ | 1.5-2.5 | 17 | 18 | 30 | 1 | 4 | 4.95 |

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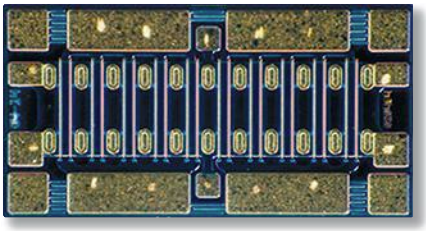

## GaN HEMT Die Delivers 30 W

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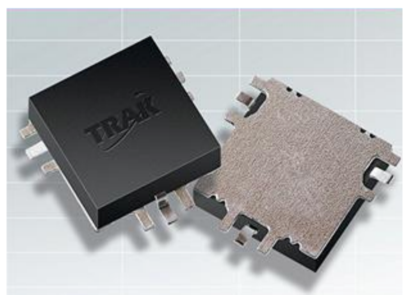


as much as 20 W continuous-wave (CW) power in a package measuring just 0.25 × 0.25 × 0.066 in. It is rated for operating temperatures from –40 to +85º and is well-suited for applications in phased-array radar antennas, communications equipment, and electronic-warfare (EW) systems. Surface-mount circulators will soon become available in slightly larger packages for use at S-band frequencies, as well as with 30% bandwidth at X-band frequencies.

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## GRASP PULSED PHASE-NOISE MEASUREMENTS

**PHASE NOISE IS** a key parameter that can limit system performance. With the development of new and more advanced RF systems, phase noise of oscillators and transmitters cannot be overlooked. In the application note, “Pulsed Phase Noise Measurements,” Rohde & Schwarz discusses phase-noise measurements of pulsed RF carriers for applications like radar systems.

The application note begins by providing a brief introduction to radar, explaining that most radar systems employ pulse modulation. Some radar velocity measurement examples are presented to demonstrate the importance of phase noise in radar systems. The characteristics of pulsed waveforms are subsequently explained in detail. Important parameters are discussed, including pulse width, pulse repetition interval (PRI), pulse repetition frequency (PRF), and duty cycle.

Phase noise of pulsed carriers is then closely examined. As an example, the spectrum of a 1-GHz carrier that is modulated with a 10-µs-wide pulse featuring a PRF of 10 kHz is presented. The document next describes the differences between pulsed and continuous-wave (CW) phase noise. A plot of both the CW and pulsed phase noise of a 1-GHz carrier is presented, followed by an explanation of why they differ from one another.

**Rohde & Schwarz, Mühldorfstrasse 15, 81671 München, Germany; 800-837-8772; www.rohde-schwarz.com**

To demonstrate the effect that pulse parameters have on phase-noise performance, three different phase-noise measurements are presented. Each measurement was made with a constant PRF of 10 kHz, but with a different pulse width. The first measurement was made using a 10-µs pulse width, which was increased to 50 µs for the second measurement. Increasing the pulse width from 10 to 50 µs resulted in improved phase-noise performance. The third measurement was made with a 1-µs pulse width. This measurement demonstrated that decreasing the pulse width from 10 to 1 µs worsened the phase noise. These measurements proved that one should not expect an oscillator’s pulsed-carrier phase noise to be the same as its CW phase noise. The application note concludes with a description of the Rohde & Schwarz FSWP phase-noise analyzer, comparing this measurement solution to traditional test methods.

## EFFECTIVELY TROUBLESHOOT MODERN RADIO LINKS

**WIRELESS TRANSMITTERS HAVE** dramatically increased in number over the last decade. The Internet of Things (IoT) has created demand for low-cost chipsets, which are based on technologies like Bluetooth, ZigBee, and Wi-Fi. Such chipsets utilize unlicensed radio spectrum like the 2.4-GHz band, which is extremely popular for low-cost, license-free applications. Unfortunately, problems are encountered in terms of establishing radio links and maintaining communications, resulting in the need for troubleshooting. In the tutorial, “Trouble-shooting Radio Links in Unlicensed Frequency Bands,” Tektronix explains why a real-time spectrum analyzer (RTSA) is an important tool for today’s troubleshooting requirements.

**Tektronix Inc., 14150 SW Karl Braun Dr., Beaverton, OR 97077; 800-833-9200; www.tek.com**

The tutorial begins by discussing the traditional spectrum analyzer, as it is the primary tool for performing spectrum-based measurements. A simplified block diagram of a traditional swept-tuned spectrum analyzer is presented. These spectrum analyzers perform swept measurements, meaning the displayed measurements are disjointed in time. Therefore, the spectral information may not be accurately represented, especially in the case of time-division multiple-access (TDMA) signals.

A block diagram of a basic RTSA is then presented. An RTSA possesses capabilities that are not available with traditional swept-tuned spectrum analyzers. For any span within the maximum real-time span, an RTSA can continuously capture spectrum information instead of having to perform swept measurements. RTSAs are also not limited to a single display at one time: Spectrum, spectrogram, and modulation information can be simultaneously analyzed. And because this data is from a continuous acquisition, the information is time-correlated.

Devices that utilize license-exempt frequency bands must withstand the effects of multiple transceivers sharing the same spectrum. Regulatory requirements almost always require that devices operating in unlicensed frequency bands cause no interference, as well as accept any interference that is present. The tutorial explains in greater detail how the capability of an RTSA to continuously capture spectrum information makes it well-suited to quantify the effects of interference. The document concludes by presenting a digital phosphor spectrum display and spectrogram from an RTSA.

JACK BROWNE | Technical Contributor

# Dual-Channel ADC Digitizes At 3 Gsamples/s

**Thanks to its 3.0-Gsample/s-per-channel sampling rate, this dual-channel analog-to-digital converter can process input signals to 4 GHz and higher.**

**HIGH-SPEED DIGITIZERS** are changing the way high-frequency systems designers approach receiver architectures. Rather than rely on mixer-based frequency-conversion receiver layout, high-performance analog-to-digital converters (ADCs) make it possible to eliminate some or all mixer stages. They enable a direct-conversion receiver method of filtering, amplifying, and then digitizing input signals.

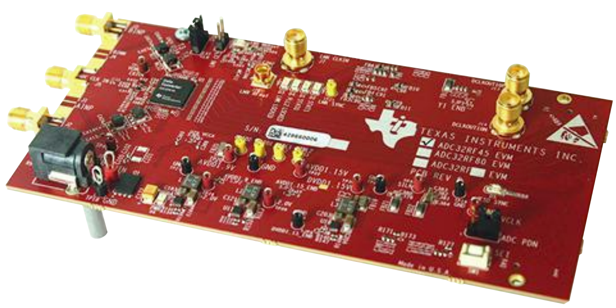
The model ADC32RF45 developed by Texas Instruments (www.ti.com) is just such a high-performance ADC. The dual-channel, 14-b ADC *(Fig. 1)* operates at 3.0 Gsamples/s per channel, supporting processing of input signals to 4 GHz and instantaneous bandwidths of 1.5 GHz per channel.

The per-channel sampling rate effectively enables digitization of modulated input signals from dc to 1.25 GHz, such as phase-modulated quadrature signals with in-phase (I) and quadrature (Q) signal components. In this fashion, a designer can capture a total of 2.5 GHz of signal spectrum (bandwidth). By packing this much processing power into one component, depending on frequency, a receiver designer can essentially eliminate at least one intermediate-frequency (IF) stage.


**1. The ADC32RF45 is a high-speed, dual-channel ADC that can digitize input signals to 4 GHz and beyond.**

### SIMPLIFYING WIDEBAND RECEIVERS

The ADC enables direct-sampled communications or S-band radar receiver designs. Buffered analog inputs have terminations for uniform input impedance across the input frequency range. The close impedance match helps minimize sample/hold glitch energy.



**2. The ADC32RF45 evaluation module comes with a power cord and USB cable for immediate testing of the ADC's capabilities.**

## ADVANTAGES OF HIGH-SPEED ADCs

**AT ONE TIME,** analog-to-digital converters (ADCs) were mainly for use at audio frequencies, where the earlier technology provided the means of converting analog inputs to digital code. However, as the technology, and the circuit-fabrication techniques to implement it, continues to mature, devices like the ADC32RF45 are emerging with capabilities to convert higher and higher analog input frequencies to digital words representing samples of those analog signals.

With complementary hardware, such as digital signal processors (DSPs) and digital filters, the captured input signals can be revitalized in the digital realm and brought back to analog form via a sufficiently wideband and high-speed digital-to-analog converter (DAC). As with any high-frequency/high-speed component, specifying an ADC for an application is largely a function of understanding the key ADC performance requirements.

Three main starting points for selecting an ADC are sampling rate, bit resolution, and bandwidth. A bit is the fundamental unit that represents digital words, typically with a value of 0 or 1. Higher resolution means more digital bits are used, in the case of an ADC, to represent an analog input waveform. An 8-b ADC, say, will provide rougher approximations of an analog input waveform than a 12- or 16-b ADC, although the higher bit resolution also requires more memory.

An ADC's sampling rate is the frequency of the clock oscillator or source that determines how many samples will be taken during a sine-wave period, capturing the frequency and voltage of the

sinewave at those sample points. According to Nyquist-Shannon sampling theory, at least two samples per period of a waveform are needed to represent that waveform in digital form. In the case of the ADC32RF45, its sampling rate of 3.0 Gsamples/s allows representation of signals to one-half the sampling frequency, or 1.5 GHz, with the sampling rate divided by two—known as the Nyquist frequency—for a given ADC.

The terms "undersampling" and "oversampling" are often used with ADCs to refer to cases where less or more than two samples per waveform period, respectively, are used to capture an analog signal in digital form. For a case where an input frequency to an ADC is less than the Nyquist frequency, more than two samples will be saved per input waveform period and thus will capture the correct frequency characteristics.

When the input frequency is greater than the Nyquist frequency, less data is captured regarding the input signal, causing a phenomenon known as aliasing. When aliasing occurs, analog input frequencies are translated into lower frequencies in the digital realm. This effect can actually be useful in some systems as a form of frequency conversion (as with an analog frequency mixer).

These are just a few of the ADC's performance characteristics. As the speeds of these components increase, they are more likely to be found in the front-ends of RF/microwave receivers, where such characteristics as signal-to-noise ratio (SNR), spurious performance, and harmonic levels come into play. An excellent review of ADC characteristics, "High-Speed Analog-to-Digital Converter Basics," written by Chris Pearson of Texas Instruments, is available on the company's website (www.ti.com).

The ADC includes a pair of dual-band digital downconverters (DDCs). Each of the ADC's channels can be connected to a dual-band DDC with as many as three independent 16-b numerically controlled oscillators, available on chip per DDC, to implement phase-coherent frequency-hopping receivers for advanced SIGINT applications. Complementary components include front-end peak and root-mean-square power detectors and alarm functions to support external automatic-gain-control circuitry and algorithms for stable ADC operation.

The digitizer achieves a robust dynamic range, with a noise spectral density of –155 dB full scale/Hz and signal-to-noise ratio of 58.5 dB at a 1.8-GHz input frequency. It accepts input signals to 1.35 V p-p. The two fully independent channels feature isolation of 95 dB for a 1.8-GHz input signal. In the time domain, the aperture jitter is an almost-negligible 70 fs.

An evaluation module (EVM) for the ADC32RF45 *(Fig. 2)* includes a clock source and voltage regulators to provide the proper power supplies for the ADC as well as a USB port. mw

TIM CAREY | Product Manager for PXI, Cobham Wireless
www.cobhamwireless.com

# Software-Defined Multi-Device Parallel Testing of Small Cells

**Small-cell device testing can be optimized by utilizing PXI architecture with advanced software.**

**GROWTH IN THE DEPLOYMENT** of small cells continues to intensify the test challenges faced by original equipment manufacturers (OEMs): They need to carry out manufacturing test at higher volumes and within tighter budgets. This article describes how automated multi-DUT testing combined with intelligent sequencing enables efficient testing of small-cell devices. Specifically, it will show how small-cell manufacturers can align and verify up to four devices in parallel on a single RF channel, achieving substantial time and cost savings.

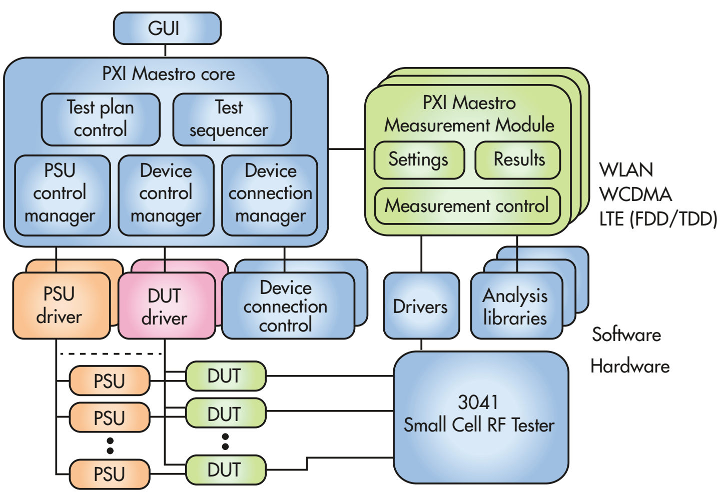
The choice of a standard tester with customizable test software also offers significant benefits compared with either the development of an in-house automated-test-equipment (ATE) system or outsourcing development to a third-party system integrator. Not only does it lower integration time, cost, complexity, and technical risk, but it reduces resources required for ongoing support and maintenance.

Recognizing the combined challenges faced by OEMs of ever-increasing product complexity, acute commercial pressures, and the need to maintain test engineering competencies, Cobham Wireless developed a family of configurable hardware and software tools based on an industry-standard PXI modular architecture. The most recent addition is the 3041 Small Cell RF Tester, which allows small-cell OEMs to run fast multi-device RF alignment and RF performance verification measurements. Advanced test software makes this possible—it manages the utilization of the equipment to ensure the shortest possible test times.

## SOFTWARE

The small-cell tester uses the PXI Maestro test-sequencing software suite. The software is designed to accelerate test system development and reduce test time, which in turn lowers test costs. A schematic of its architecture is shown in the *figure*.

Testing up to four devices in parallel can achieve productivity gains approaching 400%, and test engineering costs are just about eliminated since customer integration effort is virtually nonexistent.




**PXI Maestro software is a high-level architecture that helps reduce test times.**

## REDUCING TEST TIME

PXI Maestro reduces test time and, therefore, helps maximize production throughput thanks to highly efficient test flow management. It includes a multi-threaded intelligent sequencer that's designed to take advantage of modern multicore computers. This helps ensure that different tasks within a measurement sequence or measurement step are overlapped or executed concurrently, rather than sequentially, as is the case with conventional instrumentation.

Where multiple RF measurements are required for a single test condition, intelligent data capture is used to perform the tests in parallel on the same captured data. Acquiring a signal for measurement and processing results are decoupled, which means signal captures can be queued for processing, leading to faster test times.

It has been demonstrated that a single-channel 3041 Small Cell RF Tester can run a full calibration and test plan for LTE, WLAN, and GPS—including custom diagnostic tests—on two devices in only eight minutes. Comparatively, an existing ATE installation with two RF channels takes 12 minutes to perform the same function. Thus, the 3041 solution running PXI Maestro reduces test time by 33% while requiring 50% less test hardware.

### TESTING DEVICES IN PARALLEL

No reconfiguration or additional hardware or software elements are needed when testing multiple devices in parallel with a single tester. The tester can be configured to synchronously test between one and four devices connected in parallel. Synchronous testing is able to provide higher throughputs than sequential testing, and can be particularly beneficial for time-consuming receiver sensitivity test cases, or where device initialization times are long in comparison to validation times.

Production process flow can be further improved by testing devices in two groups of two, with the first group undergoing test while the operator loads the second group into the test fixtures. Such an approach can prove particularly efficient in cases where device handling times represent a significant portion of the overall test cycle, since it can maintain an even flow rate into and out of the test station.

### INTEGRATION COMPLEXITY

Developing, adapting, and optimizing RF test systems to cope with the constant evolution in wireless device complexity is a challenge to production-test system engineers. It is time-consuming, and requires highly skilled staff with a detailed knowledge of their test tools and the communications control interface to third-party chipset suppliers. An optimized ATE solution that is ready for testing multi-standard devices, and is software-upgradable, simplifies the process of test system integration, ultimately helping to accelerate new product introduction and saving on cost of ownership.

The simple graphical user interface (GUI) of PXI Maestro allows the test engineer to generate and execute test plans, and make application changes without any knowledge of how to control instrumentation or the device under test. Consequently, it eliminates the need to develop and maintain test-system code. All tester and device control commands are executed as an uninterrupted measurement sequence with no further user input. Measurement results are displayed as they are executed, with a final test report available in a user-friendly format.

### STANDARDS

The tester can perform accurate calibration and standards-compliant RF performance verification of LTE, UMTS, or WLAN transceivers, as well as other RF broadcast receivers such as GPS or Network Listening. It comes with a test sequencer fully integrated with device control for the Qualcomm FSM99xx family of devices, and can be easily expanded to support devices from other silicon vendors. The test system achieves all of this while retaining the inherent flexibility of its PXI modular architecture, which allows it to expand test coverage beyond RF functionality.

### CONCLUSION

The 3401 Small Cell RF Tester eliminates the need for costly and risky in-house test-system development. The cost-effective, production-ready solution easily adapts to OEMs' specific test needs and reduces the time required to ramp up to high-volume production. Moreover, it substantially shrinks test times by employing parallel testing and intelligent sequencing. mw

JACK BROWNE | Technical Contributor

# Compact SDR Scans DC to 6 GHz

**This direct-conversion SDR and its digital architecture provide the flexibility to cover many different radio communications formats and applications with one design.**

**SOFTWARE-DEFINED RADIOS (SDRs)** offer the potential to be all things to all people. With sufficient bandwidth and processing power, a single SDR can serve almost any application within its frequency range, from commercial communications to military radar and test equipment. The Crimson TNG ("The Next Generation") from Per Vices Corporation (www.pervices.com) is designed to be that single-SDR solution for applications from dc to 6 GHz.


**Packed with digital processing power, the Crimson TNG software-defined radio (SDR) supports applications from dc to 6 GHz with wide bandwidths.**

This SDR packs high-speed analog-to-digital converters (ADCs), digital-to-analog converters (DACs), and a good amount of computer processing power into a compact 1U-high rack-mount enclosure. As a receiver, it can digitize input signals quickly and accurately. As a transmitter, it can generate output waveforms with wideband modulation using four receive and four transmit channels—each with as much as 322-MHz bandwidth—for a total RF bandwidth of more than 1,200 MHz.

The Crimson TNG SDR *(see figure)* is a true single-radio solution for modern communications systems, including third-generation (3G), fourth-generation (4G), and even proposed fifth-generation (5G) cellular radio standards. It is also capable of operating within signal intelligence (SIGINT) systems, commercial and military radar systems, and test-and-measurement applications. Each of its multiple receive and transmit channels can be independently controlled, allowing the SDR to perform such functions as scanning for signals while transmitting a wide variety of modulated waveforms.

The SDR is capable of phase-coherent operation of all four transmit and all four receive channels for implementation of phase-modulated signal formats with in-phase (I) and quadrature (Q) signal components. Software support enables automatic phase calibration of the four receive and transmit channels, as well as automatic calibration of I and Q amplitude and phase imbalances, using finite-impulse-response (FIR) filtering.

The SDR is based on high-quality components, including two model DAC38J84 quad-channel DACs and four model ADC16DX370 dual-channel, 16-b ADCs from Texas Instruments (www.ti.com), along with a model 5ASTMD3E3F31I3N Arria V field-programmable gate-array (FPGA) system-on-chip (SoC) from Altera Corp. (www.altera.com). The FPGA SoC has an on-chip dual-core ARM Cortex-A9 microprocessor and web-based interface to simplify access to and remote control of the SDR. The radio's integral FPGA and built-in microprocessor combine for programmable flexibility in orchestrating almost any modulation format.

The SDR housing measures 482.6 × 500 × 43.69 mm and weighs 5.4 kg. The direct-conversion transceiver derives excellent frequency accuracy from an internal 10-MHz oven-controlled crystal-oscillator (OCXO) frequency reference with ±5-ppb stability. The SDR supports its digital components with excellent analog front-end filtering with high isolation and rejection of out-of-band signals on the receive side and suppression of spurious signal content on the transmit side.

The Crimson TNG also offers the capability for spectrum monitoring, as well as signal generation and analysis in test systems. It includes an internet interface and UHD compatibility for ease of data transport. mw

PER VICES CORPORATION, 22440 Dundas St. West, Unit 204, Toronto, Ontario M6P 1W9; (647) 534-9007, *www.pervices.com*

JACK BROWNE | Technical Contributor

# AWG Boasts Flexible Signal Generation

## With multiple output paths and several operating modes, these arbitrary waveform generators deliver analog and digital signals for present and future test requirements.

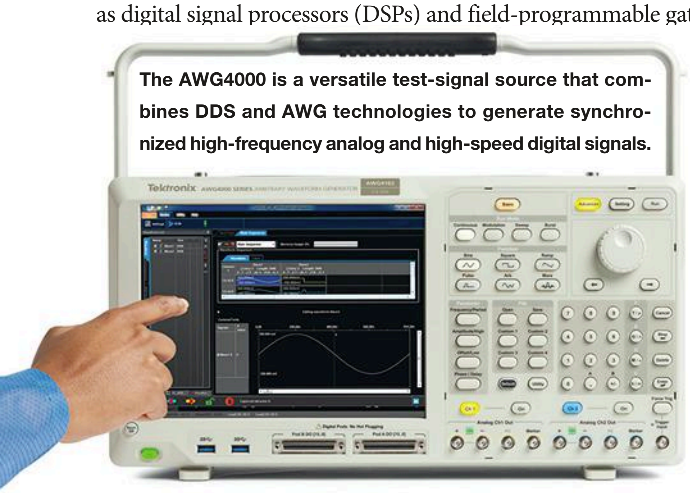
**COMMUNICATIONS STANDARDS** never stop evolving, forcing engineers to be quick on their feet when it comes to generating the correct test signals for a new standard. To help meet that need for speed, Tektronix developed the AWG4000 Series of arbitrary waveform generators (AWGs).

The AWGs offer flexibility, operating simply when a quick signal is required, or as a fully programmable arbitrary signal source for the latest waveform or exotic modulation format. With multiple output channels, sampling rates to 2.5 Gsamples/s, and 14-b vertical resolution, the AWGs can characterize the latest analog and digital circuits to 1.2 GHz and beyond.

The AWG4000 *(see figure)* is actually a 3-in-1 test-signal generator that can operate in basic, advanced, and digital signal modes. The compact instrument combines a high-speed direct-digital synthesizer (DDS) with a wideband AWG source. The DDS is the source of signals for the basic operating mode, with two analog output channels that can each generate sinewaves to 600 MHz at output levels to 5 V p-p.

### ANALOG AND DIGITAL CHANNELS × 2

The AWG can generate both analog sinewaves and different types of digital output signals when evaluating components such as digital signal processors (DSPs) and field-programmable gate arrays (FPGAs). The AWG circuitry is capable of two analog channels with up to 750-MHz modulation bandwidth each, and two digital channels with 8-b resolution and options to increase resolution to 16 or 32 b. Performance is noteworthy, since these outputs feature –60-dBc spurious-free dynamic range.




**The AWG4000 is a versatile test-signal source that combines DDS and AWG technologies to generate synchronized high-frequency analog and high-speed digital signals.**

With two digital output channels each capable of operation to 1.25 Gb/s, high-speed digital signal patterns can be created in parallel. Multiple signals are able to be time-synchronized for complex modes of testing. In addition, multiple AWG4000s can be synchronized and daisy-chained when a large number of synchronized test signals are needed.

In some cases, such as when testing digital-to-analog converters and analog-to-digital converters, mixed, digital, and analog signals may be needed. To that end, the AWG4000 can synchronize analog and digital outputs in two 16-b groups: Each signal group can be configured as lower-resolution (8-b) signals at full speed (one-half the sampling rate) or higher-resolution (16-b) signals at one-quarter the sampling rate.

The portable (14-lb.) AWG4000 includes a 10.1-in. touchscreen display and front-panel controls. It contains a removable hard disk for security, and USB 3.0 and LAN interfaces to help facilitate connection to a personal computer (PC). For local measurements, the touchscreen display simplifies the selection of different output waveforms, such as sinewaves, pulses, or square-wave signals.

The Windows-based AWG is compatible with the firm's RFXpress test software for advanced measurement programming. The AWG4000 can store and execute test signal sequences with as many as 16,384 user-defined waveforms.

Available with various feature sets, the AWG4000 is upgradable as test requirements change. For example, the basic configuration has two analog channels and no digital channels; it includes 1 Mpoint of memory for each analog channel, but can be upgraded to 16, 32, or 64 Mpoints. P&A: $34,900 and up. mw

TEKTRONIX INC., 14200 SW Karl Braun Dr., P.O. Box 500, Beaverton, OR 97077; (877) 977-0425; www.tektronix.com.

> **"As RF systems evolve, the common LO approach can be implemented in the digital realm for effective reduction of noise in observation receivers using high-speed, high-resolution ADCs and DACs."**

*(continued from p. 53)*

system, a trio of experiments were performed using an RF DAC as the signal source and an RF ADC as the heart of the sampling receiver. In the first experiment, a 10-MHz-wide "noise pedestal" was added as double-sideband noise to the RF DAC's internal phase-locked loop (PLL) reference clock *(Fig. 2a)*.

The RF DAC then produced a 1.8-GHz output signal with the double-sideband noise pedestal. This same RF DAC has the capability to provide a divided clock output, which includes noise pedestals, as the RF ADC's sampling clock.

The resulting fast Fourier transform (FFT) plot *(Fig. 2b)* was normalized to the input signal tone and compared against a spectrally pure input signal from a low-noise signal generator and a sampling clock with noise pedestals, as well as a spectrally pure input signal and clock from the RF DAC with the noise pedestals removed from the reference clock source.

The DAC's internal PLL has a loop filter bandwidth of about 6 MHz. When using the clean input from the low-noise signal generator (the green trace in Fig. 2b), the rolloff is visible. The FFT comparison reveals some interesting results.

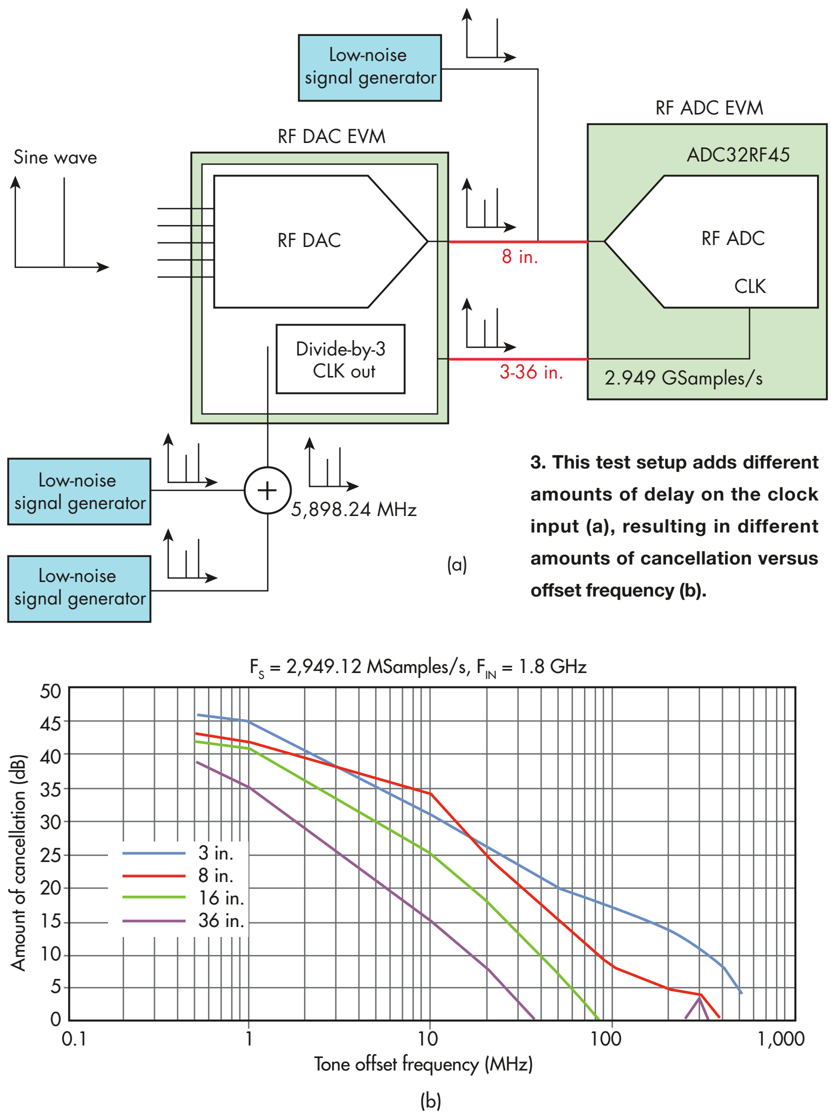
Very close (>100-kHz offset) to the carrier, the noise floor appears to be limited by the noise floor of the DAC clock output driver. At offsets from about 100 kHz to about 6 MHz, the noise pedestal receives about 25- to 35-dB attenuation, and the noise floor is close to a setup with noise removed (red trace). As the offset frequency increases, the amount of noise cancellation decreases.

The second experiment explored the effects of phase mismatches between signal and clock inputs on noise cancellation. To realize different phases leading to the two inputs, the length of the cable to the clock input was varied from 3 to 36 in., while the length of the cable to the signal input remained constant at 8 in.

As the test results clearly illustrate, larger phase mismatches between the clock and signal input lines result in more degraded performance. For optimum results, the signal and clock path lengths should be as short and as tightly matched as possible.

*Figure 3* provides a comparison of results showing how noise-cancellation performance can be improved with shorter clock input cables and longer signal input cables. This suggests that the clock routing on the evaluation and inside the ADC32RF45 is a little longer than the signal path. This is important to remember during the actual printed-circuit-board (PCB) layout, where isolation between the RF DAC and ADC may be traded off against phase mismatch.

*(continued on p. 93)*




**3. This test setup adds different amounts of delay on the clock input (a), resulting in different amounts of cancellation versus offset frequency (b).**

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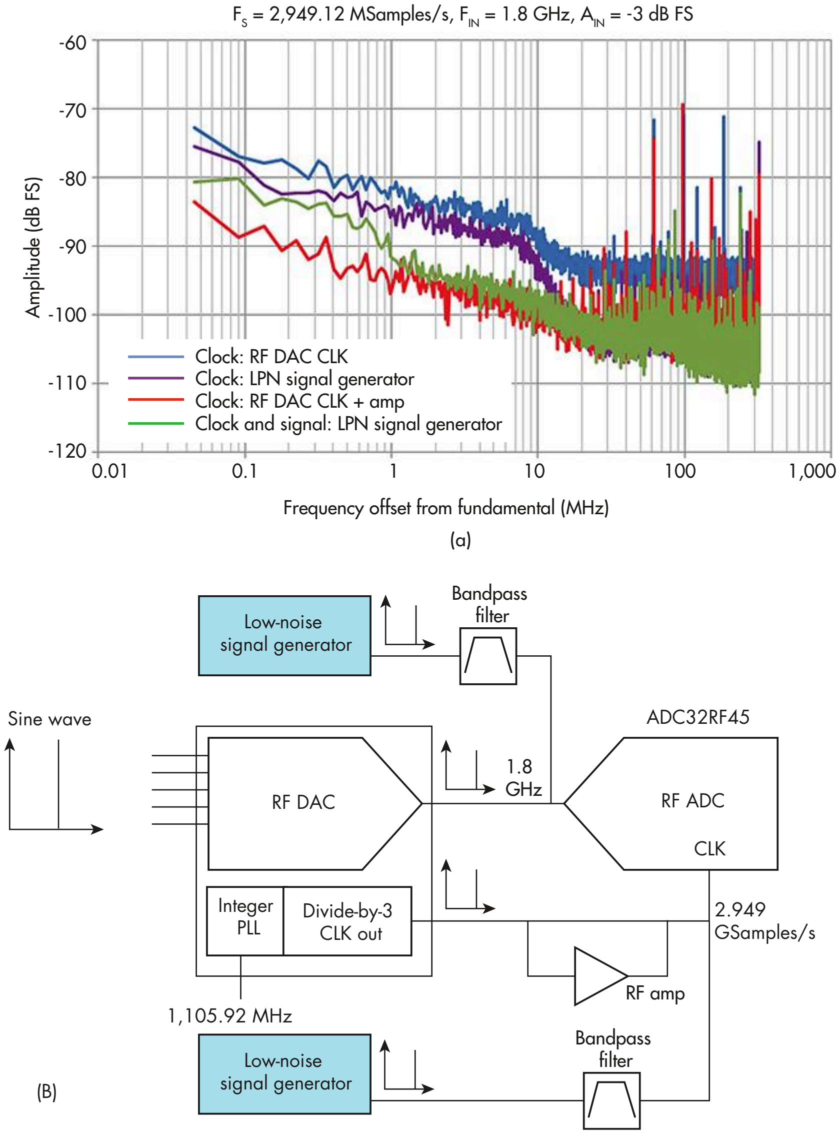
*(continued from p. 90)*

How much noise improvement can be expected in an actual system implementation of the common clock/LO approach? To find out, in the third experiment, a 1.8-GHz sine wave from the RF DAC was sampled using three different options for the ADC's sampling clock. To provide the recommended clock amplitude for the best ADC noise-floor performance, an RF amplifier was added to boost the clock amplitude *(Fig. 4a)*.

When providing a low-noise sampling clock from the low-noise signal generator, there is no noise cancellation. Hence, the PLL loop filter response is clearly visible in the output spectrum (*Fig. 4b*, purple curve). Using the clock output from the RF DAC causes the correlated noise to be cancelled. However, insufficient clock amplitude results in a high ADC noise floor that can be observed outside the PLL loop bandwidth (Fig. 4b, blue curve, for offsets greater than 10 MHz).

The best results are achieved when adding the RF amplifier in the clock path to compensate for loss in connections to and from the evaluation modules (EVMs) used to perform these experiments (Fig. 4b, red curve). Better results can be achieved when directly connecting the RF DAC clock output to the ADC clock input on the same circuit board. The far-end noise floor is now limited by the inherent thermal noise of the clock output driver and the ADC32RF45 RF sampling ADC, while the close-in, correlated noise experiences noise cancellation.

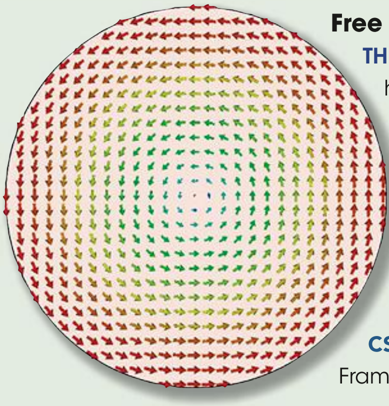



**4. In this experiment, system performance was compared with different sampling clock options (a), with the resulting FFT noise-floor performance (b).**

The inherent thermal noise of the DAC clock output is worse when compared to the low-noise floor of the low-noise signal generator with a bandpass filter (Fig. 4b, green curve), which occurs with offsets greater than about 50 MHz. However, by taking advantage of noise cancellation, the close-in noise performance (<30 MHz offset) of the RF DAC clock output is actually better (lower), despite its inherently worse internal PLL noise.

The three experiments described above show that the common LO approach for transmitter noise cancellation can also be applied to RF sampling data converters when used in mixed-signal transmitters and receivers. Such RF data converters offer the capabilities to digitize signals in the RF range with wider instantaneous bandwidths than lower-frequency IF data converters, and can also take advantage of the same noise-cancellation capabilities as traditional IF-sampling-based data converters. mw

*Editor's Note: The ADC32RF45 is a dual-channel, 14-b analog-to-digital converter (ADC) that features a maximum sampling rate of 3.0 Gsamples/s. It can effectively digitize input signals to 4 GHz or higher with wide modulation bandwidths, for implementation of low-component-count, direct-conversion receivers. For a full review on the new ADC, don't miss this month's feature beginning on page 80.*



### Free Software Provides EM Simulation for Students

**THE NEWEST RELEASE OF CST STUDIO SUITE**—Student Edition is a free version of the highly regarded electromagnetic (EM) simulation software that now includes a low-frequency solver for analyzing eddy currents. The versatile software is like a textbook in code form. It contains time-domain, frequency-domain, static, and thermal solvers along with a set of online examples on how to simulate classic EM problems at undergraduate and post-graduate learning levels. The new low-frequency frequency-domain (LF-FD) solver can be applied to the analysis of eddy currents in such components as sensors, actuators, and transformers. The student software is available for free download from the CST website.

**CST OF AMERICA, INC.**, 492 Old Connecticut Path, Ste. 500, Framingham, MA 01701; (508) 665-4400, *www.cst.com*

### Flexible Test Cables Make Right-Angle Connections

**A FAMILY OF FLEXIBLE TEST CABLES** includes right-angle connectors. The low-profile test-cable assemblies cover a total frequency range of dc to 27 GHz with 16 unique assemblies, including dc to 27 GHz for SMA assemblies and dc to 18 GHz for Type-N and TNC assemblies. The right-angle SMA and Type-N connectors incorporate an internal radius design to optimize performance in a low-profile configuration. The cable assemblies, which are available with 0.086- and 0.141-in. diameters and with double-shielded, silver-plated copper braid over silver-plated copper tape, offer low insertion loss, typical VSWR of 1.25:1, and isolation of 90 dB or more. They include an operating temperature range of –40 to +150°C and stainless-steel connectors rated for a minimum lifespan of 500 mating cycles.

**PASTERNACK**, 17802 Fitch, Irvine, CA 92614; (949) 261-1920, *www.pasternack.com*



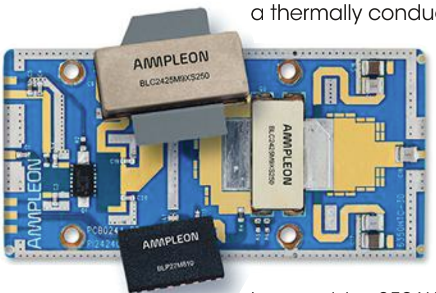
### Low-Power I/Q Modulator Spans 0.7 to 6.0 GHz

**BATTERY-POWERED ELECTRONIC PRODUCTS** require devices that can run on low power, and the LTC5589 in-phase/quadrature (I/Q) modulator is such a device. It operates from 700 MHz to 6 GHz on a single +2.7- to +3.6-V dc supply while consuming only 29.5-mA current. It features sideband suppression of –50 dBc and typical carrier leakage of –43 dBm without calibration. The modulator offers excellent transmitter performance, with output third-order-intercept point of +19 dBm and a low output noise floor of –158.8 dBm. It achieves a baseband bandwidth as wide as 92 MHz with RF bandwidth of 184 MHz at 1.8 GHz. The device supports narrowband and wideband transmitter applications, including portable field radios, unlicensed band radios, train communications, software-defined radios (SDRs), portable RF test equipment, low-power microwave backhaul and repeaters, telemetry radios, and satellite modems. It comes in a 4- × 4-mm plastic QFN package with operating temperature range of –40 to +105°C. P&A: $4.45 (1000 qty.); stock.


**LINEAR TECHNOLOGY CORP.**, 1630 McCarthy Blvd., Milpitas, CA 95035-7417; (408) 432-1900, *www.linear.com*

## Reference Design Warms to Solid-State Heating

**THE MICROBLAZE 250** is a miniature solid-state power-amplifier reference design capable of 250-W output power from 2.4 to 2.5 GHz. Based on silicon LDMOS transistor technology, it measures just 80 × 40 × 5 mm and can be used in microwave ovens and industrial heating systems in place of vacuum-tube electronics. The modular design employs a thermally conductive copper base plate and the firm's unique BLC2425M9XS250 ACP-3 air cavity package with its model BLP27M810 power transistors. The reference design provides 250-W output power at 1-dB compression with 36-dB gain when fed with a +21-dBm input signal. It runs from a +32-V dc supply and consumes 20-A current. The amplifier can withstand VSWR mismatches as severe as 10.0:1 for 60 s without damage and is designed for operating temperatures from +5 to +100°C.




**AMPLEON NETHERLANDS B.V.**, Halfgeleiderweg 8, 6534 AV Nijmegen, The Netherlands; (31) 6 208 14 771, *www.ampleon.com*

## Software-Defined VNA Sweeps 125 MHz to 6 GHz

**AN AFFORDABLE BUT HIGHLY ACCURATE** software-defined vector network analyzer (VNA) provides high-resolution S-parameter measurements from 125 MHz to 6 GHz. The compact model 6a analyzer is designed for network operation, with the possibility of controlling and displaying results from multiple VNAs on a single personal computer (PC)—each VNA being identified by its own IP address. Ideal for production environments requiring multiple test stations, this VNA maintains a high dynamic range even at fast sweep rates, making it well suited for testing a range of passive components, such as antennas, attenuators, cables, and filters. Typical dynamic range at a sweep rate of 45 kHz is 72 dB at the lowest frequencies and 56 dB at 6 GHz. The typical dynamic range at a sweep rate of 2 kHz improves to 84 dB at 125 MHz and 69 dB at 6 GHz. The VNA's open, flexible application-programming-interface (API) software provides the freedom to create custom sweep patterns to fit any production test requirements.


**AKELA INC.**, 5551 Ekwill Dr., Santa Barbara, CA 93111; (805) 683-6414, *www.akelavna.com*